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# DEVELOPMENT OF A CANADIAN ARCTIC BRIDGE NAVIGATION SIMULATOR: VALIDATION OF A SHIPHANDLING MODEL

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Un sommaire en français de ce rapport est inclus avant la Table des matières.

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17 Abstract

This study is aimed at the preliminary development and operational validation of an Arctic Shiphandling Simulation Model for use on the first Canadian Bridge Navigation Simulator (CABINS). The mathematical basis of the ice force algorithm used in the simulation model incorporates quasi-static representation of hull forces due to forward movements in level unbroken ice. The simulator utilizes state-of-the-art hydrodynamic models for other aspects of shiphandling simulation. Models for the R-Class vessels and the U.S. Polar Class vessels were developed and verified using available full scale data. Operational evaluation of the complete simulation model was carried out independently by two Canadian Coast Guard captains. The scenario used for the evaluation exercises consisted of the icebraking vessel approaching and attempting to free a beset caro ship in ice cover of uniform thickness as well as varying thickness. Each captain carried out a total of twelve exercises in two days, based on which they ranked the ship performance model on a scale of 1 to 10. Final evaluation included fidelity of navigation bridge instruments, visuals, radar image and the gaming area. It is concluded that the demonstration of CABINS as a full bridge navigation simulator was successful and the simulation model implemented and validated on CABINS is satisfactory as a preliminary model for shiphandling in ice. Recommendations for further developmental work on CABINS are outlined that will improve its potential as a research and training tool.

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17. Résumé
Cette étude a pour objectif la mise au point et la validation opérationnelle d'un premier logiciel de simulation des manoeuvres d'un navire dans l'Arctique à être exploité par le premier simulateur de passerelle de navire canadien (CABINS). Le fondement mathématique de l'algorithme des forces glacielles servant à la simulation est une représentation quasi statique des forces subies par la coque du navire avançant dans une couche de glace uniforme et intacte. Quant aux autres aspects de la simulation, ils sont pris en charge par des modèles hydrodynamiques évolués. Des modèles ont été étudiés pour la simulation du comportement de navires de classe R et de classe Polar des Etats-Unis, leur validation s'étant faite à l'aide de données en vraie grandeur. L'évaluation opérationnelle du logiciel de simulation complet a été menée séparément par deux capitaines de la Garde cotière canadienne. Le scénario retenu pour l'exercice d'évaluation était celui d'un brise-glace s'approchant d'un cargo pris dans les glaces pour le dégager, l'épaisseur de la couche de glace étant, au choix, uniforme ou variable. Chacun des capitaines a réalisé au total 12 exercices en deux jours, cotant les performances du modèle de simulation sur une échelle de 1 à 10. L'évaluation globale portait entre autres sur la fidélité des instruments de navigation, la précision des images radar et le réalisme des visualisations et de l'environnement représenté. Les chercheurs ont conclu que l'expérimentation du simulateur de passerelle de navire CABINS avait été une réussite et que le logiciel de simulation mis en oeuvre et validé sur CABINS donnait des résultats satisfaisants pour un premier logiciel de simulation des manoeuvres dans les glaces. Le rapport trace les grandes lignes des travaux de perfectionnement proposés pour accentuer les possibilités du CABINS à titre d'instrument de recherche et de formation.

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# SUMMARY

The safe operation of ships in the Canadian Arctic has been the subject of much recent research supported by Transport Canada. The feasibility of developing a land-based bridge navigation simulator for Arctic shipping research was investigated in 1983 which concluded with the definition of the operational requirements of such a simulator. The study also recommended that work be started with the procurement of a small open-water navigation simulator that can be adapted subsequently for simulation of ships in ice. A year later, a set of performance specifications was written for an ice-capable simulator which outlined the basic hardware requirements and the software capabilities. Within a few years, a commercial initiative was underway at Fleet Technology Limited (formerly Arctec Canada Limited), to construct a small research simulator, which was later named CABINS. Based on the built-in capabilities of this facility, a proposal was subsequently submitted to the Transportation Development Centre (TDC) of Transport Canada that would bring together much of the earlier work by applying the results in a practical way to the development of preliminary ice capabilities in CABINS. The present report summarizes the findings of a project funded by TDC in response to the above proposal, which undertook the development, implementation and validation of an Arctic Marine Simulation Model.

The Canadian Bridge Navigation Simulator (CABINS) was designed and installed to fill the perceived gap in the ship simulation capability across the country. With the necessarily wide range of tasks the simulator would be required to carry out, CABINS was designed to be of modular construction so as to be flexible and adaptable to a wide range of vessels and operations. The system is based on a network of micro-processors that produces computer-generated imagery (CGI) for visual display required for nocturnal simulation. At present three projectors are used to display the CGI on a 120 degree screen and can show as many as 200 lights at an update rate of 15 times a minute. CABINS is operated by one instructor who has full control of the exercise. Tugs, target ships, their speeds and courses, winds and currents can all be controlled from the instructor's console. Records of exercises are kept by plotting the exercise area showing the shorelines, buoys, etc. as well as printing the courses and speeds of own ship and target ship. The mathematical models residing in the system are especially designed to be able to cope with the large range of operations required and can incorporate effects such as bow and stern thrusters, dynamic positioning systems, bow propellers, tugs and close interaction effects.

In this project, the objectives were to perform a study with CABINS, utilizing available full scale data of ship's turning performance in level ice, and to develop a ship-handling model that will allow case studies of a number of ship operations in ice to be carried out. The data used have been collected over the past seven years and recently applied to the validation of mathematical models developed previously ("Manoeuvring Tests in Ice Aboard USCGC POLAR STAR in Antarctica 1985", by Menon, B., Edgecombe, M., Tue-fee, K., and Glen, I.F., 1986, TP8297E).

The study has resulted in a "pilot" set of simulation-oriented ice navigation software that will permit a more rational assessment of the hardware and software requirements for a full-mission ice navigation capability.

In the model development for vessel manoeuvres in level ice, the chosen methodology treats the ice effect as additional hull forces to be evaluated in modular form. The basis of the ice force formulation developed in TP8297E is closely followed, which assumes that the forces on the hull are a direct function of the mass of the ice disturbed. The main divergence from the previous methodology is the abandonment of the zero drift angle assumption. The force system on the hull due to ice consists of longitudinal and lateral forces on the bow, a lateral force on the parallel midbody, a longitudinal stern force caused by friction and the bow and stern moments caused by the lateral forces. The usual method of incorporating transient forces and moments is to establish a number of quasi-steady states at each iteration, and then apply a time lag to proceed from one quasi-steady state to another.

The icebreaking vessels chosen for modelling were the Canadian R-Class and the U.S. Polar Class ships. Mathematical models for both the above types of vessels were developed, verified and validated.

A number of system modifications to CABINS were necessary to fulfill the requirements of this project. These can be divided into five specific areas:

1) design and implementation of a new gaming area and creating the associated water depth, two-dimensional and three-dimensional visual data bases.

2) general system changes to facilitate the selection of a specific gaming area, ship model and ice thickness data base.

3) specific changes made to produce and use ice thickness data bases and to include ice forces in the force model algorithm.

4) modification of the radar display to show an ice edge when needed and to show a ship track for both the target and own vessels.

5) modifications to the visual generation program to enhance the presentation of a target vessel when it is nearby.

It is generally accepted, that the suitability of a simulator for a particular task can only be determined through an operational evaluation of its performance. Clearly an operational assessment of the accuracy of the simulations is dependent upon one's real life experience. It was felt that a fair basis for judgement of validity was one in which two captains were operating the simulator with ship models that were reasonably close in performance to vessels they have piloted.

Captain Pat Toomey of the Canadian Coast Guard was the skipper of the CCGS PIERRE RADISSON, an R-Class vessel for a number of years. He has also been onboard the USCGC POLAR SEA, a Polar Class vessel, during icebreaking operations. He has been an officer aboard various Canadian icebreakers since the 1960's. Captain Eric Hann of the Canadian Coast Guard has as well vast icebreaking experience. He has commanded the CCGS JOHN A. MACDONALD and the CCGS LABRADOR, both of which are reasonably close to the vessel types chosen for this study. Based upon the experience of both captains, it was felt that the two chosen ship types were highly valid for evaluation purposes.

A generalized exercise area was agreed upon with the two captains. A two-dimensional data base was then created. The data base, measuring 6000 m x 5000 m, contains X, Y coordinate information regarding the shorelines and shorelights. This information is used to create images generated by the radar, plotter and instructor computers. Next a water depth data base was constructed based upon the above coordinate system. The gaming area was divided into 480 squares, measuring 250 m to a side, with a value assigned to the center point of each square. The water depth at any location within the gaming area is calculated by linear interpolation between the nearest central grid points in both the X and Y directions. Lastly, a three-dimensional data base of stationary lights (shorelights, buoys, lighthouses, etc.) is created. This data base contains X, Y and Z coordinate data along with colour, flashing characteristics, and visibility information.

The two icebreaker captains performed a total of 24 exercises in four days. Each captain performed twelve exercises and used the R-class ship model in the first six exercises and the Polar Class Ship model in the second six exercises. Each of the six exercises was carried out in a different gaming area, namely:

Exercise 1: in half ice/half water
Exercise 2 (A&B): in level ice
Exercise 3 (A&B): in varying ice thickness
Exercise 4: in varying ice thickness with different grid size

At the end of each exercise, the graphical output from the different manoeuvres and the model validation form filled in by the captain were put together to form the data set used for presenting and comparing the results. In addition to these, each captain provided his own comments about the simulation process in general and the exercises in particular, by completing a detailed evaluation questionnaire. The graphic and printed output from the exercises along with comments recorded on tapes and the captain's evaluation report provided the basis for preparing the final validation statement as well as the perceptual fidelity assessment, as described below.

The model validation form completed at the end of every exercise was used to determine the level of realism of the simulation process. This was done by tabulating the ratings assigned by each captain to the model performance parameters.

A higher percentage indicates a higher level of realism. Comparing the evaluations of both captains, shows that the R-class model was 68.5% realistic and the Polar Class model was 69% realistic.

Each captain, after performing twelve exercises, completed an evaluation form in which he judged the degree of realism of each bridge instrument, the level of adequacy of 'out of window' visuals and the fidelity of the radar simulated image. They were also allowed to express their comments on the models, the visuals, the scenarios and the communication procedures. As a whole, the average assessment of the two captains showed that the above mentioned items were 76% realistic.

In evaluating the model performance, both captains emphasized the importance of simulating the broken channel behind own ship, which has a significant influence on the captain's decisions and choices of the various techniques using in freeing a beset ship.

Capt. Toomey indicated that the ship's model is not entirely realistic while turning. In a real-life situation, when the ship loses its headway in ice, she cannot turn to port or starboard. On the simulator, the ship continued turning, thereby making that aspect of simulation longer than the experience would be onboard a real ship.

It should be noted that the captains have experience in operating the R-Class ships only, and both of them indicated that they could notice the difference in ship performance when they exercised the Polar Class model on the simulator. This emphasizes the benefits of using the simulator in training, especially when the trainee has no real life experience onboard a specific type of ship.

Both captains emphasized the fact that the nocturnal view was barely sufficient for the simulation process. They also pointed out that the daylight graphics are essential to help the ice navigator in:

(a) Determining the distance between own ship and target ship in close quarter situations. In real life, the distance estimation depends greatly on the ice navigator's visual judgement.

(b) Identifying the thickness, type and condition of ice. This identification helps the ice navigator to choose the appropriate manoeuvre.

While having only nocturnal view, the captains mentioned that the simulation of own ship engine-noise and the sounds of ship-ice interaction will improve the trainee's perception of realism in the simulation.

Capt. Toomey indicated that the configuration of lights onboard the target ship was sufficient, but the number of lights on the deck and stern was not. The height of the light, from a distance less than 0.5 nautical miles, was, apparently, too high and unrealistic. Also, because of the limitations of the graphics, there was no silhouette for the target ship, which caused some difficulty in judging the distance between the two ships.

The scenarios were sufficient for testing the model performance but were too simple to be used in training. However, present scenarios would be too simple to force the trainees to perform difficult manoeuvres. Both captains agreed that the most realistic simulation of model performance and manoeuvrability would be in thick ice, especially with a fine grid size for thickness variation.

A number of specific conclusions were drawn as a result of the operational evaluation:

° The hydrodynamic models developed for the R-Class as well as the Polar Class vessels are judged to be about 70% realistic. This indicates that the modelling approach is essentially sound and the assumptions used are justifiable.

° The degree of realism that can be associated with the bridge set-up and display is estimated as 76%.

° One of the captains judged the mathematical models for steady turning in ice to be adequately realistic, while the other found it wanting in realism. It is concluded that improvements to the ice force algorithm will require more full scale data.

° There was unanimous agreement in the inadequacy of nocturnal vision for simulations in ice. This was expected and future efforts in development will aim for daylight vision.

° Scenarios selected were judged to be effective in aiding the operational evaluation. Hence future work can use the present approach as a reliable starting point for planning of validation exercises.

Recommendations for improving the capabilities of CABINS for shiphandling in ice were drawn up as outlined below:

° Enhancement of 'out of window' visuals to include daylight graphics with control over the degree of visibility.

° 'Out of window' visuals to be expanded to cover 360° or a minimum of 180°. This is deemed to be a major requirement for training.

- Further development of the mathematical models for simulation of ahead and astern manoeuvres in broken ice as well as discontinuities in level ice cover due to broken channels.

- Influence of grid size on model performance.

- Modification of radar image to provide higher resolution and increased update rate.

# SOMMAIRE

Au cours des dernières années, Transports Canada a financé de nombreuses recherches ayant eu pour thème la sécurité des navires évoluant dans les eaux arctiques canadiennes. Dès 1983, une étude de faisabilité concernant la mise au point, au sol, d'un simulateur de passerelle de navire aux fins de la recherche sur la navigation dans l'Arctique, avait permis de définir les exigences opérationnelles concernant un tel simulateur. Cette même étude avait recommandé de commencer par l'acquisition d'un petit simulateur de navigation en eau libre qui pourrait être adapté par la suite à la simulation des manoeuvres dans les glaces. Un an plus tard, un devis de performance était rédigé, définissant les besoins fondamentaux en matériels et logiciels d'un simulateur de manoeuvres dans les glaces. Quelques années plus tard, Fleet Technology Limited (antérieurement Arctec Canada Ltd.) lançait sur initiative privée un projet de construction d'un petit simulateur de recherche, dénommé ultérieurement CABINS. Se fondant sur les possibilités propres de cette installation, cette entreprise a par la suite présenté une proposition au Centre de développement des transports, Transports Canada, visant à réunir les résultats de la plupart des travaux antérieurs dans une application pratique destinée à adapter le simulateur CABINS à la simulation dans les glaces. Le présent rapport récapitule les conclusions de la recherche financée par le CDT et dont l'objectif était, aux termes de la proposition précitée, d'étudier, de réaliser et de valider un logiciel de simulation de la navigation dans l'Arctique.

Le simulateur de passerelle de navire canadien (CABINS) avait été conçu et réalisé afin de combler ce qui était perçu à la grandeur du pays comme une lacune de notre système d'enseignement et de formation en navigation maritime. Compte tenu de la gamme forcément très étendue des tâches que ce simulateur devait pouvoir réaliser, il a été décidé qu'il serait de construction modulaire assurant souplesse et adaptabilité à une grande variété de types de navires et d'opérations maritimes. Il s'agit d'un appareil construit autour d'un réseau de microprocesseurs qui produit une imagerie informatisée de type visualisation de nuit. À l'heure actuelle, la visualisation se fait au moyen de trois projecteurs sur écran de 120°, un maximum de 200 feux lumineux pouvant être affichés à une fréquence de 15 mises à jour à la minute. CABINS est piloté par un seul instructeur qui règle tous les aspects de l'exercice à partir de son pupitre: position des remorqueurs, des bateaux cibles, vitesses et caps, vents et courants. Un imprimé du déroulement de l'exercice peut être obtenu sous la forme d'une carte de la zone d'exercice montrant le rivage, les bouées, etc., complétée d'un listage des caps et vitesses des bateaux concernés. Les modèles mathématiques utilisés ont été étudiés exprès pour pouvoir traiter la gamme étendue des manoeuvres à simuler et prendre en compte différents effets spéciaux comme la présence de propulseurs d'étrave et arrière, de systèmes de positionnement dynamique, d'hélices d'étrave, de remorqueurs, ainsi que les effets d'interaction approchée.

L'objectif de cette étude était d'élaborer, en se servant du simulateur CABINS et de données en vraie grandeur de giration dans les glaces, un modèle de simulation de manoeuvres qui permettra d'étudier le déroulement d'un certain nombre d'opérations dans les glaces. Les données utilisées ont été recueillies au cours des sept dernières années et avaient récemment servi à la validation des modèles mathématiques élaborés dans le cadre d'une étude antérieure intitulée "Manoeuvring tests in ice aboard USCGC Polar Star in Antarctica 1985", B. Menon et al., Arctec Canada Ltd., 1986, TP 8297E. L'étude a débouché sur un "jeu pilote" de logiciels de simulation de la navigation dans les glaces qui permettra une évaluation plus rationnelle des besoins en matériels et logiciels d'une installation capable de simuler toute la gamme des manoeuvres envisageables dans les glaces.

L'élaboration du modèle de simulation des manoeuvres dans une glace uniforme se base sur une méthodologie qui assimile les glaces à des forces additionnelles s'exerçant sur la coque du navire et dont l'appréciation doit se faire sous forme modulaire. La méthode de formulation des forces glacielles élaborées dans le rapport TP 8297E est étroitement suivie, méthode qui pose comme hypothèse que les forces s'exerçant sur la coque sont une fonction directe de la masse de glace déplacée. La principale innovation par rapport à cette méthode est l'abandon de l'hypothèse d'un angle de dérive nul. Le système de forces glacielles s'exerçant sur la coque se compose de forces longitudinales et latérales sur l'étrave, d'une force latérale sur la section médiane rectangulaire du navire, d'une force longitudinale sur l'arrière attribuable à la friction et de moments d'étrave et de poupe liés aux forces latérales. La méthode normale de prise en compte des forces et moments transitoires consiste à établir un certain nombre d'états quasi permanents à chaque itération et d'appliquer alors un décalage temporel permettant de procéder d'un état quasi permanent au suivant.

Les brise-glace retenus pour la modélisation étaient des navires canadiens de classe R et des navires américains de classe Polar. Des modèles mathématiques figurant les deux types de navires ci-dessus ont été élaborés, vérifiés et validés.

La réalisation des objectifs de la présente étude a nécessité un certain nombre de modifications du simulateur CABINS, réparties dans cinq domaines distincts:

1) synthèse et mise en place de nouvelles zones d'exercice, et création de bases de données concernant la profondeur d'eau et les visuels bi et tridimensionnels associés;
2) modifications globales des paramètres d'exploitation en vue de faciliter la sélection de la base de données en fonction d'une zone d'exercice, d'un type de navire et d'une épaisseur de glace donnée;
3) modifications ponctuelles visant à produire et à exploiter des bases de données sur l'épaisseur des glaces, et à prendre en compte les forces glacielles dans l'algorithme de modélisation des forces en jeu;

4) modification de la simulation radar de manière à afficher, au besoin, la ligne de démarcation couche de glace/eau libre, ainsi que le chenal ouvert aussi bien par le brise-glace que par le bateau cible à secourir;

5) modification du programme de synthèse d'images de manière à rehausser la visualisation du bateau cible en vue rapprochée.

On s'entend généralement pour dire que seule une évaluation opérationnelle des performances permet de déterminer si un simulateur donné convient ou non à la tâche particulière considérée. L'expérience propre de l'évaluateur ayant de toute évidence un effet déterminant sur l'appréciation de la justesse des simulations, il a été décidé que pour assurer la validité de l'évaluation, on ferait appel à deux capitaines, lesquels seraient invités à procéder à des simulations mettant en oeuvre des modèles de navires dont les caractéristiques de comportement sont raisonnablement proches de ceux qu'ils avaient pilotés. Ainsi, le capitaine Pat Toomey de la Garde côtière canadienne (GCC) a déjà été le commandant de bord du PIERRE-RADISSON, un brise-glace de classe R, durant un certain nombre d'années. En plus d'avoir été officier à bord de divers brise-glace canadiens depuis les années 60, celui-ci a vécu l'expérience d'opérations de déglaçage à bord du USCGC POLAR SEA, un navire américain de classe Polar. Quant au capitaine Eric Hann, également de la GCC, il cumule lui aussi une vaste expérience à titre de capitaine de brise-glace, notamment du JOHN A. MCDONALD et du LABRADOR, des navires affichant des caractéristiques raisonnablement proches de celles des navires retenus pour les fins de la modélisation. Compte tenu de l'expérience des deux capitaines, les responsables de l'étude pensent que les deux modèles de navire retenus conviennent parfaitement aux fins de l'évaluation.

Après avoir déterminé de concert avec les deux capitaines les caractéristiques générales de la zone d'exercice, les chercheurs ont créé une base de données bidimensionnelle représentant une zone de 6000 mètres sur 5000 mètres où la position des lignes de rivage et des feux de signalisation maritime est repérée par des coordonnées rectangulaires (X, Y). Cette base de données sert à la génération assistée par ordinateur d'images radar, cartographiques et autres commandées par l'instructeur. Par la suite, une base de données des profondeurs d'eau a été créée, fondée sur le système de coordonnées précité. La zone d'exercice a été divisée en 480 mailles carrées, de 250 mètres de côté, le point central de chaque maille étant affecté d'une valeur particulière. La profondeur d'eau en tout point de la zone pouvait donc être calculée par interpolation linéaire entre les points centraux de maillage les plus proches dans les deux axes X et Y. En dernier lieu, les chercheurs ont créé une base de données tridimensionnelle pour la représentation des feux stationnaires (feux à terre, bouées, phares, etc.). Cette base de données renferme des coordonnées XYZ ainsi que des informations sur la couleur, le rythme de clignotement et la visibilité des feux.

Les deux capitaines ont procédé à 24 exercices au total en quatre jours. Chacun a commencé par six exercices sur navire de classe R avant de passer au modèle Polar pour les six suivants. Les six exercices se passaient dans des zones différentes:

| | | |
|---|---|---|
| Exercice 1 | | moitié glace/moitié eau libre |
| Exercice 2 | (A et B) | glace uniforme |
| Exercice 3 | (A et B) | glace d'épaisseur variable |
| Exercice 4 | | glace d'épaisseur variable et étendue de maillage différente |

À la fin de chaque exercice, le relevé graphique des différentes manoeuvres exécutées et le formulaire de validation rempli par le capitaine étaient amalgamés pour constituer le jeu de données utilisé pour la présentation et la comparaison des résultats. En plus, chaque capitaine faisait part de ses observations personnelles sur la simulation en général et le déroulement des exercices en particulier, grâce à un questionnaire d'évaluation détaillé. L'évaluation définitive de la validité du logiciel de simulation est fondée sur les relevés graphiques et imprimés des différents exercices, les commentaires enregistrés sur ruban et les rapports d'évaluation des capitaines, tout comme l'appréciation du réalisme des visuels (voir ci-dessous).

Le formulaire de validation du modèle, rempli à l'issue de chaque exercice, servait à déterminer le degré de réalisme de la simulation. Il s'agissait de compiler les cotes attribuées par les deux capitaines à l'égard des différents paramètres de performance du modèle. Plus la cote est élevée, meilleur est le degré de réalisme. La moyenne des deux évaluations s'établissait à 68.5 p.100 pour le modèle concernant les navires de classe R et à 69 p.100 pour ceux de la classe Polar.

Après avoir exécuté les 12 exercices prévus, chaque capitaine a rempli un formulaire d'évaluation dans lequel chacun d'eux se prononçait sur le degré de réalisme des instruments de la passerelle, la qualité des visualisations extérieures et la fidélité de l'imagerie radar simulée. Ils pouvaient aussi faire des observations sur les modèles, les visualisations et les scénarios ainsi que sur les procédures de communication. Pour l'ensemble des éléments précités, la moyenne des deux évaluations s'établissait à 76 p.100 pour ce qui est du réalisme.

Dans leur évaluation du modèle de simulation, les deux intéressés ont souligné l'importance de représenter le chenal ouvert dans le sillage du navire piloté, un élément déterminant dans les décisions du capitaine quant au choix de la technique à utiliser pour libérer un navire pris dans les glaces.

Selon le capitaine Toomey, la modélisation du comportement des navires n'est pas tout à fait réaliste en giration. Dans la réalité, le navire qui arrive en bout d'erre ne peut plus virer ni à bâbord ni à tribord, alors que la simulation montre le navire continuant à virer.

Il est à noter que l'expérience des deux capitaines se limitait à des navires de classe R. Malgré cela, tous les deux ont indiqué pouvoir faire la différence entre le comportement de cette classe de navire et celui du modèle Polar simulé. Cette constatation rehausse l'utilité de la formation sur simulateur, surtout lorsque le stagiaire n'a aucune expérience pratique d'un type de navire particulier.

Les deux capitaines ont fait remarquer que la visualisation de nuit convenait à peine pour les besoins de la simulation. Ils ont aussi souligné qu'une visualisation de jour était essentielle pour aider le pilote à:

a) déterminer la distance entre son navire et le bateau cible dans les situations de manoeuvre rapprochée. Dans la réalité, l'estimation des distances dépend beaucoup de l'observateur considéré.

b) reconnaître l'épaisseur, le type et l'état de la glace, autant de facteurs dont la connaissance aide le pilote à choisir la manoeuvre qui convient.

À ne disposer que d'une visualisation de nuit, les deux capitaines sont d'avis qu'une simulation du bruit des machines du navire piloté et du choc des glaces aurait pour effet de rehausser le réalisme de l'exercice.

D'après le capitaine Toomey, la configuration des feux définissant la position du bateau cible était appropriée, mais le nombre des feux sur le pont et l'arrière du navire ne l'était pas. Pour un éloignement simulé de moins de 0,5 mille marin, la hauteur des feux était apparemment trop grande et, partant, non réaliste. Aussi, à cause du caractère sommaire du graphisme, l'absence de silhouette du bateau cible rendait difficile l'estimation juste des distances entre les deux navires.

Les scénarios convenaient pour les essais de validation du modèle, mais ils étaient trop simplistes pour les besoins de formation. En effet, leur simplicité est telle que les stagiaires ne seraient pas amenés à réaliser des manoeuvres difficiles. Les deux capitaines s'entendaient pour dire que le réalisme de la simulation des performances et de la manoeuvrabilité serait le plus poussé dans le cas d'un scénario prévoyant une épaisse couche de glace, surtout avec un maillage fin de variation d'épaisseur.

L'évaluation opérationnelle a débouché sur les constatations suivantes:

- Le réalisme des modèles hydrodynamiques élaborés à l'égard des navires de classe R et de classe Polar a été coté à environ 70 p.100, laissant entendre que la technique de modélisation retenue est essentiellement valable et que les hypothèses de départ se justifient.

- Le degré de réalisme de l'aménagement de la passerelle et des visualisations s'établit à 76 p.100.
- Les deux capitaines diffèrent d'opinion quant au réalisme des modèles mathématiques de giration uniforme dans les glaces: suffisamment réaliste pour l'un, ils manquaient de réalisme pour l'autre. La conclusion qui s'impose est que l'amélioration de l'algorithme des forces en jeu passe par l'acquisition de données plus complètes en vraie grandeur.
- Tous conviennent que la visualisation de nuit ne convient pas pour la simulation des manoeuvres dans les glaces. C'était prévu et il est d'ores et déjà décidé de faire porter les efforts sur la mise au point d'une visualisation de jour.
- Les scénarios ont été jugés appropriés pour les besoins de l'évaluation opérationnelle. Par conséquent, les travaux à venir pourront bâtir sur l'approche actuelle pour la définition des exercices de validation.

Les recommandations concernant l'extension des possibilités du CABINS sur le plan de la simulation dans les glaces sont les suivantes:

- Rehaussement des visualisations extérieures par la synthèse d'images diurnes à degré de visibilité réglable.
- Extension de la visualisation extérieure sur 360° ou à tout le moins 180°. Cette amélioration serait essentielle aux fins de formation.
- Perfectionnement des modèles mathématiques de manière à permettre la simulation de manoeuvres en marche avant et arrière dans un champ de glaces brisées et aussi pour le franchissement de chenaux ouverts dans la couverture de glace.
- Etude de l'influence de la densité de maillage sur les performances du modèle.
- Modification de l'imagerie radar par un rehaussement de la résolution et l'accélération de la cadence de balayage.

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# 1. INTRODUCTION

## 1.1 Background

The safe operation of ships in the Canadian Arctic has been the subject of much recent research supported by Transport Canada. The feasibility of developing a land-based bridge navigation simulator for Arctic shipping research was investigated in 1983 which concluded with the definition of the operational requirements of such a simulator. The study also recommended that work be started with the procurement of a small open-water navigation simulator that can be adapted subsequently for simulation of ships in ice. A year later, a set of performance specifications was written for an ice-capable simulator which outlined the basic hardware requirements and the software capabilities. Within a few years, a commercial initiative was underway at Fleet Technology Limited (formerly Arctec Canada Limited), to construct a small research simulator, which was later named CABINS. Based on the built-in capabilities of this facility, a proposal was subsequently submitted to the Transportation Development Centre (TDC) of Transport Canada that would bring together much of the earlier work by applying the results in a practical way to the development of preliminary ice capabilities in CABINS. The present report summarizes the findings of a project funded by TDC in response to the above proposal, which undertook the development, implementation and validation of an Arctic Marine Simulation Model.

In this project, the objective was to perform a study using CABINS, that utilized available full scale data of ship's turning performance in level unbroken ice, and develop a ship-handling model that would allow case studies of a number of ship operations in ice to be carried out. The data used have been collected over the past seven years and recently applied to the validation of mathematical models developed under an earlier project [7]. The study has resulted in a "pilot" set of simulation-oriented ice navigation software that will permit a more rational assessment of the hardware and software requirements for a full-mission ice navigation capability.

## 1.2 The Canadian Arctic Bridge Navigation Simulator (CABINS)

About two years ago, Fleet Technology Limited in association with Maritime Dynamics Limited of Wales, U.K., designed and installed CABINS to fill the perceived gap in Canada's bridge simulation capability. With the necessarily wide range of tasks the simulator will be required to carry out, considerable efforts have been made to ensure that the design is flexible and adaptable to a wide range of applications. The ability to generate new ship types and operating areas rapidly as well as in a cost-effective manner were perceived to be one of the primary requirements. A degree of environmental fidelity to cater to the needs of trainees was also considered a prime requisite. The ability to expand the facility as needs and budget demand, as well as the capability to enhance the ship manoeuvring model to include ice operations regimes, was high on the agenda for further development.

Using local area networks, ten micro-processors form the heart of the computing system within CABINS. The system can be easily upgraded or degraded according to the complexity needed, as it is of modular construction. This feature also makes the system easily maintainable. Overhead RGB projectors are used to display the computer-generated image (CGI) on a curved screen (Figure 1.1). The software is capable of handling 360° vision around the bridge with up to 200 lights shown simultaneously at a minimum update rate of 12 - 15 times a minute. Depending on the complexity this rate can be substantially increased. CABINS is operated by one instructor who has full control of exercise initiation, tugs, target ships, speeds and courses, winds, gusts and currents. During the simulation, the instructor will have a replication of the bridge out of the window view. The instructor has access to any part of the exercise area at any time during the run and has control over the scale of target ships on the screen. He also has a recording facility for every exercise in two forms:

- Plotting the exercise area showing all the shore lines, lighthouses, light buoys and the tracks of his own ship and target ship, all in different colours;
- Printing courses and speeds of own ship and target ships in the form of a table as a function of time.

The plotting and printing are done at pre-specified intervals by the instructor.

The mathematical models which reside in the system are especially designed to be able to cope with the large range of operations required. They are fully valid at low and zero speeds and can incorporate the range of effects such as bow and stern thrusters, dynamic positioning systems, bow propellers, tugs and close interaction with wind and wave effects.

## 1.3 Basic Design Features

The main distinguishing features of CABINS are the flexible bridge layout and the total use of linked microcomputers in the design. The overall schematic diagram of the simulator is shown in Figure 1.2. It will be seen that the simulator is based around a computing network of individual microcomputers. While each of these in itself can be very simple and inexpensive, the total computing power is reasonably large, and certainly able to cater for the very stringent needs of a research or port design simulator. The precise nature of the computers used in any particular installation or indeed application, will vary according to the task requirement. A very flexible network is used, allowing any computer to access the memory of any other, and any IBM or Acorn compatible computer may be installed at any point in the network. With the Acorn range extending to a 32 bit RISC architecture machine, with a computing power in excess of many large superminis, there is no effective restriction on computer power for any task.

FIGURE 1.1 BRIDGE AND EQUIPMENT LAYOUT IN CABINS

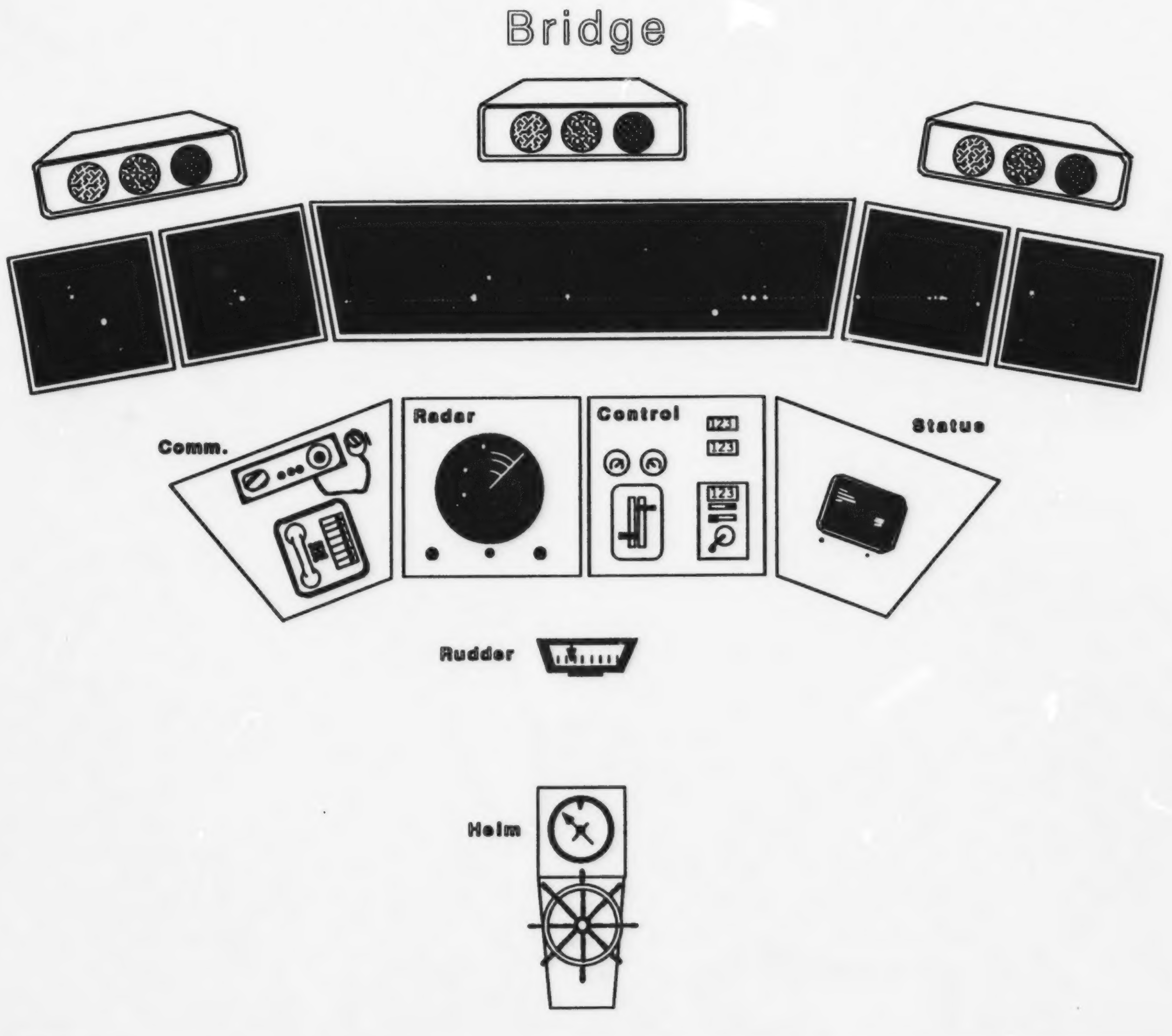
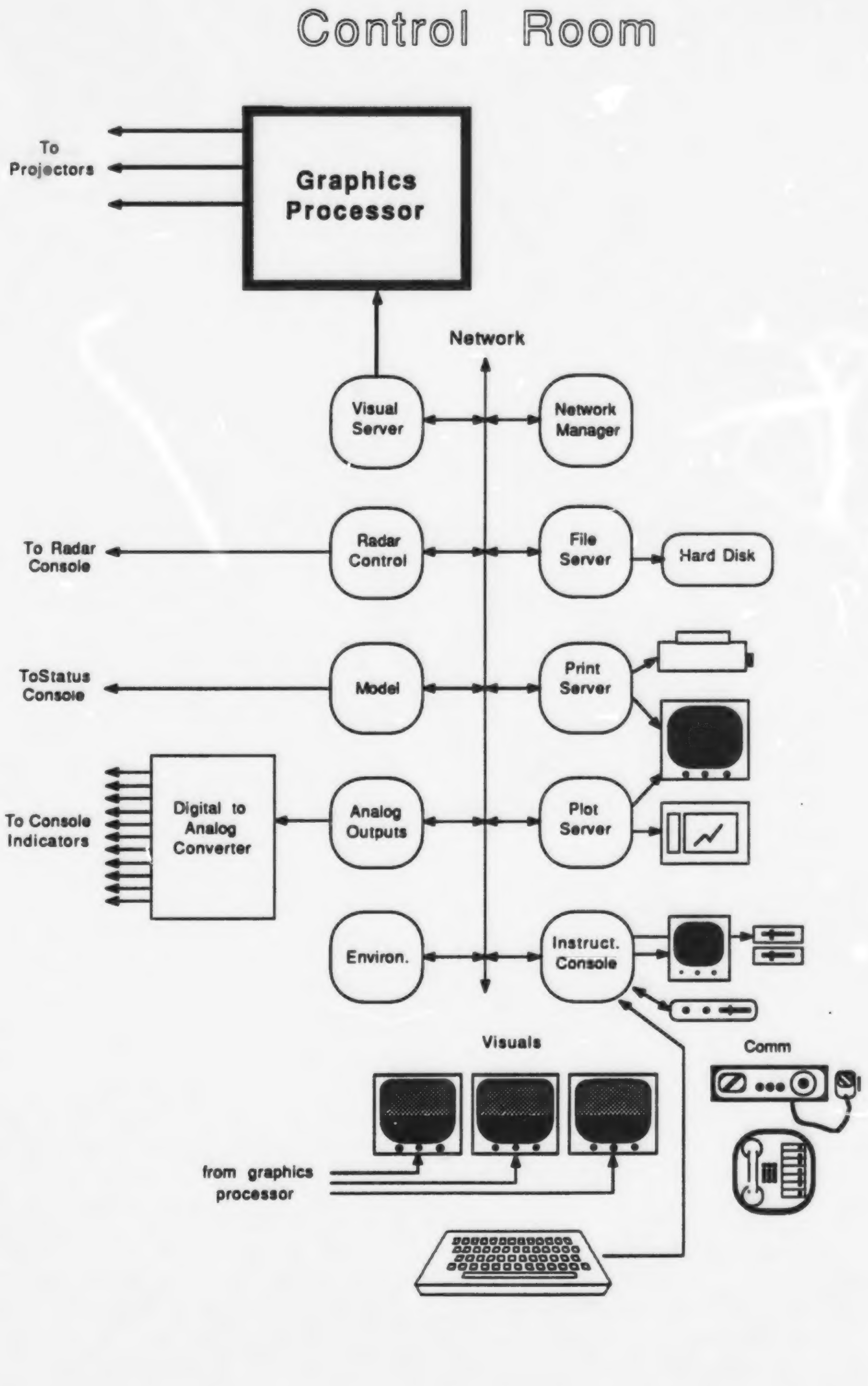

Bridge
Comm.
Radar
Control
123
123
123
Status
Rudder
Helm

FIGURE 1.2 SCHEMATIC OF COMPUTER, CONTROL AND DISPLAY SYSTEMS


Control Room
To Projectors
Graphics Processor
Network
Visual Server
Network Manager
To Radar Console
Radar Control
File Server
Hard Disk
ToStatus Console
Model
Print Server
To Console Indicators
Digital to Analog Converter
Analog Outputs
Plot Server
Environ.
Instruct. Console
Visuals
Comm
from graphics processor

Where it is required to install other computers, such as for a visual system, this is done using any normal protocol, such as RS232. At present, CABINS uses mainly simple 6502 processors for most tasks, but the central computing engine is shortly to be boosted in power to allow for the inclusion of ice forces.

## 1.4 Visual Systems

At present, CABINS is fitted with an advanced nocturnal visual system, with three horizontal channels. Over 500 lights may be shown, by CGI techniques, and the usual features, of correct flashing characteristics, fading of light intensity with range, and reduced visibility, are present. The visual system, using a number of 68000 based computers, is interfaced to the simulator network by a simple passive RS232 link. This enables the visual system, like any other part of the simulator to be changed as requirements alter. For example, the nocturnal system does not show land features, as these are not readily visible at night. There is therefore some difficulty in using the system for close quarters work, where the shape of the shore and other navigational features may be of interest. In these cases, other visual systems may be used. Other compatible visual systems can be brought into use simply by changing the input and video outputs.

Current research effort is directed towards finding an optimal spacing for lights used to define the edges of a shore feature. For example, if a row of closely spaced lights is placed around the edge of an offshore rig, the lights may be able to be used to give the mariner the necessary distance and motion cues, once he is familiar with the appearance of the rig. The use of lights in this way is only possible where there are several hundred to choose from. At present the system has the option of two visual systems, the 500 light nocturnal system, and a simple daylight CGI system, VISARS.

## 1.5 Bridge Provision

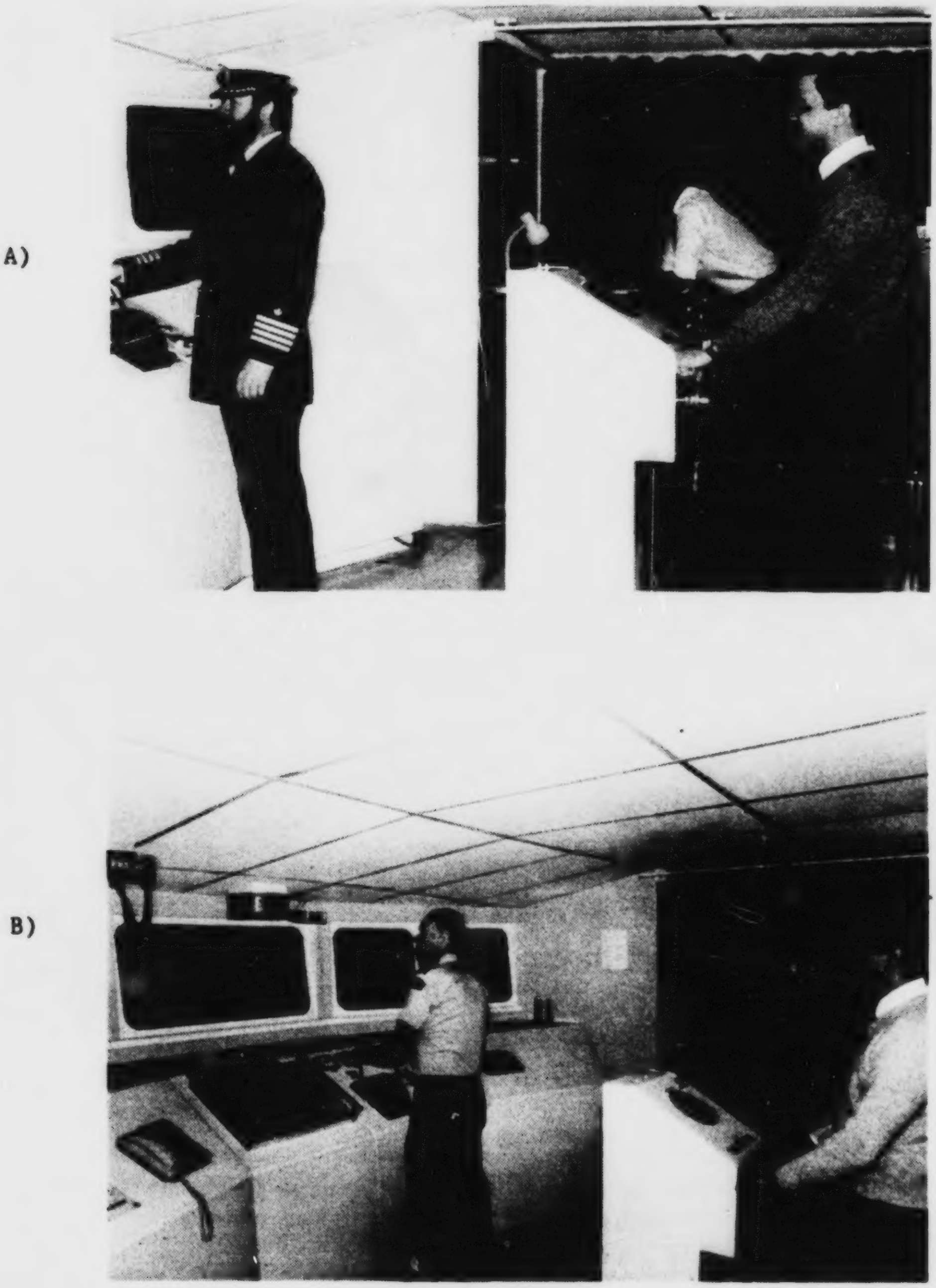
The CABINS visual scene is projected onto three screens, using front projection techniques over the bridge top. The bridge instrumentation fit is partly produced by hard wired instruments of the conventional kind, showing rudder angle, ship's head, etc., and partly by a VDU, showing doppler log, rate of turn, wind speed and direction, and actual telegraph settings. An advantage of using VDU techniques is that additional or changed information can be very simply provided. The instrumentation fit is under the control of a specialized intelligent interface microcomputer, so that its programming is very simple and does not affect the remainder of the computation.

Similarly, the hard wired ship controls are fed to another intelligent interface, so that as requirements change, the inputs to the computing net can be altered by simply changing that one computer. The controls are on a removable panel, so that they may also be changed to suit different ship types.

The radar provision is at present a simulated North-Up display, with controls let into the console, to represent the behaviour of a typical ship radar. It is recognized that this is a minimal fit for many applications. However, the use of a dedicated microcomputer as a radar node allows for the interfacing of any other, more sophisticated radar simulation to be provided as required, again without disturbing the overall simulator provision. For many applications, though, where the chief requirement of the radar is to give additional position information to the mariner, this provision is entirely adequate. It fails totally to provide comprehensive radar training experience, but it is not intended to do so.

A conventional steering stand is used with an indication of ships head, and provision for an autopilot. Simulated internal and external communications are fitted and displayed. Figure 1.3 (a) and (b) show CCG captains performing the evaluation task on CABINS.

FIGURE 1.3 OPERATIONAL EVALUATION BY CCG CAPTAINS



## 2. MATHEMATICAL MODELS AND FULL SCALE DATA

### 2.1 Review of Mathematical Models for Simulation of Ship Manoeuvres

At the heart of the ship simulator is the mathematical model. The model, which is embedded into the system computer, accepts commands from the "bridge" and produces outputs representing the dynamic behaviour of the vessel in response to those commands and to the various environmental influences present at the time. These environmental influences are under the control of the instructor and will normally include the effects of: Wind, current, shallow water (including squat and bank effects), waves, other ships (interaction), tug, mooring and anchoring forces. The degree to which these effects will be required, and the resulting complexity of the mathematical model, will depend entirely on the purpose for which the model is to be used. The three commonly used types of models are described below:

Type A, Hydrodynamic Derivative Model: In a conventional model of this type the behaviour of the ship is modelled by three force equations, representing the motion of the ship in each of the three degrees of freedom, surge, sway and yaw. Each equation consists of a series of polynomial terms of a Taylor expansion. The basic form of the model is described by Gill [2]. Each term in the expansions is associated with a coefficient or hydrodynamic derivative, whose value is determined in a number of ways, with a great reliance being placed on results of towing tank tests involving a scale model of the ship. A separate mathematical model is required for slow speed manoeuvres, (necessarily associated with high drift angles), and the two models are merged at about 2 knots forward speed. This type of model is widely used in ship simulators, and is capable of handling the full range of ship and environment.

Type B, Simple Force Model: This model was developed by McCallum [3]. Also of the force type, with three coupled equations in surge, sway and yaw, the model differs from Type A in that the equations are developed in a conventional way, by analyzing the forces and moments acting on the ship in a direct manner. Only one set of equations is required to represent the ship behaviour in all manoeuvring regimes. Model coefficients are evaluated from theoretical considerations, standard results and from ship trial results, and because of the direct method of analysis, there is a direct and identifiable relationship between the model coefficients and the ship behaviour. The model is used in a wide range of ship and radar simulators worldwide.

Type C, Heuristic Model: In order to meet a need for even faster and cheaper model development, principally for offshore navigation training, a very basic form of mathematical model is also in use. This model is based on the familiar Nomoto model [4], with the addition of a speed equation, a simple engine model, and a sway equation, to get it into the same format as the other ship models. This model is very simplistic, but has been used effectively in a number of training courses in CASSIM. Its main advantage lies in the speed and cost effectiveness of model development. Because of its simple structure, it is not considered to be suitable for port design work and other complex simulation applications. Table 2.1 lists the relative advantages and disadvantages of the three types of model.

## TABLE 2.1

## MATHEMATICAL MODELS - ADVANTAGES AND DISADVANTAGES

| TYPE | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| A | Widely accepted model<br>Wide range of application | Two models required for whole range of operation<br>New models costly to produce<br>Ship-model validation difficult<br>On-site optimization difficult |
| B | Relatively easily produced<br>One model only required<br>Easy to optimize performance<br>Wide range of applicability<br>Fast model development time | Ship trial results usually required |
| C | Very fast to produce<br>Very easy to optimize performance on site | Too simple for many applications<br>Will not adequately represent unstable ships<br>Lacks "feel" of ship |

## 2.2 Requirements of Full Scale Trial Data on Vessel Manoeuvring Performance

### 2.2.1 Types of Full Scale Data Required

The primary source of data for simulating navigation in ice is full scale trials. This is the commonly followed approach for all simulator related work as full scale tests take into account all realistic variations of the environment, the vessel operations and the human interference. The results of the full scale trials are then used to validate the mathematical models driving the simulations. In the absence of full scale data, model test data is relied upon for comparison with simulation. Some of the important parameters of the data base and their significance are shown in Table 2.2. The data can be categorized into two groups:

- Data from trials in ice with the ship proceeding straight ahead - provides hull resistance in ice in the continuous mode of icebreaking at various speeds and ice thicknesses.
- Data from turning trials in ice - provides turning circle diameter, initial turning rate, magnitude of drift angle, etc. at specified ship speed, rudder angles and ice thicknesses.

No standardized methods exist for obtaining data on ship-ice interaction in other modes such as interaction with either large ice floes, or edge of an ice shelf or impact with bergy bits. Collection of this type of data will require special methods and dedicated trials.

### 2.2.2 Overview of Available Data

Model and full scale ice resistance data collected from a variety of sources, with vessels proceeding straight ahead, has been recently re-analyzed in reference [5]. The availability of this data is shown in Table 2.3. The overall full scale ice resistance data is considered to be the most extensive in the western world. Model scale ice resistance data for the CCGS PIERRE RADISSON provides enough data, to accurately predict the ice resistance and validate the prediction with full scale results.

Model scale data for the other seven ships of Table 2.3 is not as extensive but is considered sufficient for simulation of straight ahead motion. Values of missing data such as thrust, torque, model speed, etc. of the model scale self-propelled ships can either be deduced with reasonable accuracy or alternative methods adopted. Transient modes such as accelerating and decelerating (in a straight line) can be introduced by accounting for the inertial effects of the ice, water, ship, etc., by using the standard physical laws of force and acceleration.

## TABLE 2.2

## REQUIREMENT OF FULL SCALE AND MODEL SCALE DATA

| PARAMETERS | APPLICATION |
|---|---|
| SHIP - body plan | Provides the bow geometry which affects the icebreaking pattern and energy imparted to the ice |
| - principal particulars | Identifies the ship type and enables manufacture of geometrically similar model |
| SHIP STABILITY PARTICULARS - roll period, pitch period, metacentric height, etc. | Affects ship's dynamic characteristics, which in turn affects the turning capability in ice |
| RUDDER(s) - area, cross-section, centre of pressure, etc. | Determines the influence of the rudder(s) on the turning capability |
| RUDDER ANGLES USED | Provides the turning moment applied to the ship |
| PROPELLER(s) - diameter, number of blades, shape and profile, fixed or controllable pitch, etc. | Provides information on the thrust and torque that can be developed by the propellers in ahead and astern modes and for stopping and starting the ship |
| PROPELLER THRUST, TORQUE AND RPM | Provides information on the power delivered to propel the ship |
| MAIN PROPULSION MACHINERY; SIZE AND NUMBER OF ENGINES | Provides the developed horsepower available. |
| TYPE OF ENGINES -steam, diesel, gas turbines, electric, etc. | Affects engine response time and stopping distances. |
| REDUCTION GEARING | Affects ahead to astern response time. |
| THRUSTERS | Affects ship's turning capabilities at slow speeds and when stopped. |
| SHIP SPEED | Provides information on the power delivered and the performance of the hull form. |

TABLE 2.2 (continued)

| PARAMETERS | APPLICATION |
|---|---|
| ICE - level, floes, bergy bits, etc., amount of cover, first year, multi-year, consolidated, etc. | Affects the visual clues as well as ship/operations suitable for these ice conditions. |
| ICE THICKNESS, STRENGTH, MODULUS, ETC. | Provides information on resistance to steady motion in level unbroken ice. |
| HULL/ICE FRICTION COEFFICIENT | Provides information on resistance to steady motion in level unbroken ice. |
| SNOW COVER | Provides information on resistance to steady motion in level unbroken ice. |

## TABLE 2.3 Available Ice Resistance Data

| Type of Tests | | Parameter | Ship | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Manhattan | Mackinaw | Katmai Bay | Radisson | St. Laurent | Alexander Henry | Wolfe (new bow) | Staten Island | Arctic | Vladivostock | Finncarrier | Jelparri |
| FULL SCALE TRIALS | | $T_B$ | ✓ | | ✓ | ✓ | ✓ | ✓ | | | | | | |
| | | $Q_B$ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | ✓ | |
| | | $N_B$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | $V_S$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ? | ✓ | ✓ | ✓ |
| | | H | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ? | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | $\sigma_f$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ |
| | | Snow | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | | $\mu$ | | ✓ | ✓ | ✓ | ✓ | | ✓ | | | | | |
| | | | | | | | | | | | | | | |
| MODEL TESTS | TOWED | R | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| | | $V_S$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| | | h | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| | | $\sigma_f$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| | | $\mu$ | ✓ | | ✓ | ✓ | ✓ | ? | | | ✓ | ✓ | ✓ | ✓ |
| | | | | | | | | | | | | | | |
| | SELF PROPELLED | $T_B$ | Tank Test Data Not Available | | | ✓ | | | | | ✓ | | | |
| | | $Q_B$ | | | | ✓ | | | | ✓ | ✓ | | | |
| | | $N_B$ | | | | ✓ | | | | ✓ | ✓ | | | |
| | | $V_S$ | | | | ✓ | | | | ✓ | ✓ | | | |
| | | h | | | | ✓ | | | | ✓ | ✓ | | | |
| | | $\sigma_f$ | | | | ✓ | | | | ✓ | ✓ | | | |
| | | $\mu$ | | | | ✓ | | | | | ✓ | | | |
| | | | | | | | | | | | | | | |

| | | | |
|---|---|---|---|
| $T_B$ | Thrust (behind) | Snow | Snow Cover |
| $Q_B$ | Torque (behind) | $\mu$ | Hull Ice Friction Coefficient |
| $N_B$ | Propeller Speed | R | Hull Resistance in Ice |
| $V_S$ | Ship's Speed | V | Model Speed |
| H | Ice Thickness | h | Ice Thickness |
| $\sigma_f$ | Flexural Strength of Ice Cover | ? | Questionable Data |

Full scale trials conducted to measure manoeuvring characteristics of ships in ice have been examined and the quality and quantity of data published has been found to be limited. One of the early documented full scale turning data is for the CCGS PIERRE RADISSON and consists of seven turning circle trials with ice thickness data available for five of these trials [6]. The total range of results available for the RADISSON and other ships is shown in Table 2.4.

Another set of full scale data recently gathered and analyzed [7] came from the 1985 Antarctic deployment of USCGC POLAR STAR. Three separate sets of turning manoeuvres were conducted from which a total of 19 data points are available. Results generally confirmed predictable trends as to the effect of rudder angle, power level and ice thickness on turning radius. They were somewhat clouded by an inability to maintain a thrust balance between the two wing propellers. Port turns were substantially sharper than those to starboard under similar operating conditions.

As indicated earlier, full scale results are used mainly to verify the accuracy of simulation. The paucity of full scale results, therefore, does not necessarily mean that simulated results will not be acceptable but merely that they will need to be further validated.

### 2.2.3 Summary

As is usual with full scale trials data, the available information forms the data base of the R-Class and the Polar Class vessels. The useful manoeuvring performance data, falls far short of that required for ship manoeuvring simulation models. The analyzed data are exclusively in steady state form and the essential data on transient manoeuvres are almost totally absent. It is understood, however, that the archived Polar Class data include information on unsteady manoeuvres which may be analyzed in the future for the purposes of refining and validating the mathematical models developed under this project. For both vessels, open water performance data are very limited. Where it is necessary to produce open water ship manoeuvring models from inadequate data, one approach is to produce some pseudo-data, either from another validated ship manoeuvring model, or from knowledge of the manoeuvring behaviour of ships of similar types. A problem with icebreakers is their special hull form which gives unusual open water manoeuvring performance.

## 2.3 Selection of Ship Models

There are three possible approaches to the selection of mathematical models which can be adopted for this project. These are:

- The Hydrodynamic Derivative Model
- The Force Model
- The Heuristic Model

## TABLE 2.4

## COMPARATIVE TURNING CIRCLE DATA FOR ICE CAPABLE SHIPS (FULL SCALE)

| RUDDER ANGLE ° | R/L | ICE THICKNESS (m) | DEPTH OF SNOW (m) | ICE BENDING STRENGTH (kPa) | TOTAL THRUST (kN) | TOTAL THRUST / BOLLARD THRUST |
|---|---|---|---|---|---|---|
| CCGS PIERRE RADISSON | | | | | | |
| 35 S | 14 | 1.0 | 0 | 208 | 445 | 0.35 |
| 35 P | 13 | 1.0 | 0 | 208 | 445 | 0.35 |
| 35 S | 10 | 1.0 | 0 | 208 | 445 | 0.35 |
| 20 S | 14 | 1.0 | 0 | 208 | 445 | 0.35 |
| 20 P | 20 | 1.0 | 0 | 208 | 445 | 0.35 |
| 35 P | 7.92 | .66 | .11 | 475 | 471 | 0.38 |
| USCGC POLAR STAR | | | | | | |
| 10 S | 23.8 | 1.12 | 0 | 180 | 924 | 0.21 |
| 20 S | 6.4 | 1.12 | 0 | 180 | 1106 | 0.28 |
| 19 P | 4.2 | 1.12 | 0 | 180 | 1198 | 0.29 |
| 17 S | 8.4 | 0.84 | 0 | 127 | 929 | 0.22 |
| 20 P | 3.7 | 0.93 | 0 | 127 | 898 | 0.18 |
| 22 S | 7.2 | 0.93 | 0 | 127 | 1023 | 0.25 |
| 26 P | 3.2 | 1.02 | 0 | 180 | 1010 | 0.26 |
| 21 P | 4.1 | 1.02 | 0 | 180 | 831 | 0.17 |
| 23 S | 8.1 | 0.93 | 0 | 127 | 836 | 0.17 |
| 17 P | 5.3 | 0.93 | 0 | 127 | 823 | 0.16 |
| 22 S | 8.6 | 0.84 | 0 | 127 | 790 | 0.13 |
| 22 S | 5.4 | 1.63 | 0 | 228 | 1506 | 0.41 |
| 15 P | 3.5 | 1.49 | 0 | 228 | 1216 | 0.36 |
| 22 S | 4.3 | 1.49 | 0 | 228 | 1438 | 0.37 |
| 11 P | 3.9 | 1.35 | 0 | 228 | 1175 | 0.29 |
| 19 P | 3.7 | 1.35 | 0 | 228 | 1214 | 0.36 |
| 19 S | 5.3 | 1.49 | 0 | 228 | 1446 | 0.37 |
| 14 P | 4.1 | 1.49 | 0 | 228 | 1221 | 0.36 |
| 18 S | 4.4 | 1.63 | 0 | 228 | 1454 | 0.37 |

These models were described in Section 2.1. Both the Force Model and the Heuristic Model are available in CABINS at the present time. Hydrodynamic Derivative models usually require a physical model to be produced and tested in a towing tank to produce the necessary derivatives. The only exception to this is if a very similar ship has been modelled before and only small changes are required. In the present case, where the ships are so different in their behavior from the normal type of merchant ships, two models would need to be made and tested. For the Force Model, there is an identifiable and logical relationship between the model coefficients and the ship behaviour. Models can therefore be generated from inadequate data.

Both the Hydrodynamic Derivative and the Force Models are fully able to accept Ice Forces separately calculated in independent modules. Some ice manoeuvring models totally neglect the effect of the hydrodynamic forces, on the assumption that the ice forces are very large compared with the hydrodynamic forces at low icebreaking speeds. This view is not shared for the following reasons:

- In thin ice the assumption that the ice forces predominate is no longer true as the magnitudes of the ice forces are lower and the forward speeds are higher and so the model breaks down.

- The normal ship manoeuvring model presents a valid framework into which the ice forces may be inserted. Without such a framework, the representation of ice in a manoeuvring situation may prove difficult.

- The normal manoeuvring models are well understood.

The heuristic model type is not considered to be adequate for representing ice forces to any accuracy. The model is made up by asking the user what effects he wishes to see, and producing the simplest expressions which enable this to be done. Although there is, by definition, a high level of user acceptance of this model, the approach is not at all rigorous, and the essential force information is not present.

It was decided to use the Force Model for this project.

# 3. TRANSIENT MODEL FOR VESSEL MANOEUVRES IN ICE

## 3.1 Background

The underlying modelling methodology employed is to consider the ice forces acting on the ship as additional forces to be evaluated as part of the Modular Mathematical Model [8 and 3]. The basic structure of the model is shown in Figure 3.1, where all the relevant hydrodynamic and environmental forces are deduced in their own modules, and added together to obtain the accelerations acting on the ship.

The ice forces and moments are therefore calculated by analyzing the way in which the passage of the ship causes the ice to build up and therefore to act on the ship. The methodology of [1] is closely followed where practical, for reasons of consistency and simplicity. The main assumption, that the ice forces acting on a manoeuvring ship may be considered as a direct function of the mass of ice disturbed, is supported and used for the calculation of the ice forces.

The main divergences from the methodology of [1] are:

- In order to facilitate modelling of the dynamic behaviour of the ship in all manoeuvring regimes, the ice forces are treated as only one of the many hull forces. Thus, the initial assumption of [1], that the hydrodynamic forces are small compared with the ice forces, is not used.

- The zero centre drift angle assumption [1] is relaxed. Instead, a more general computation is used, allowing for any drift angle.

## 3.2 Assumptions

Many of the assumptions used in this analysis are similar to those employed in [1] and are listed below:

- Ice force prediction is at present confined to the case where the icebreaker is operating in the ahead mode. Ice forces are assumed to be negligible in the astern mode as the icebreaker may then be considered to be retreating through its broken channel.

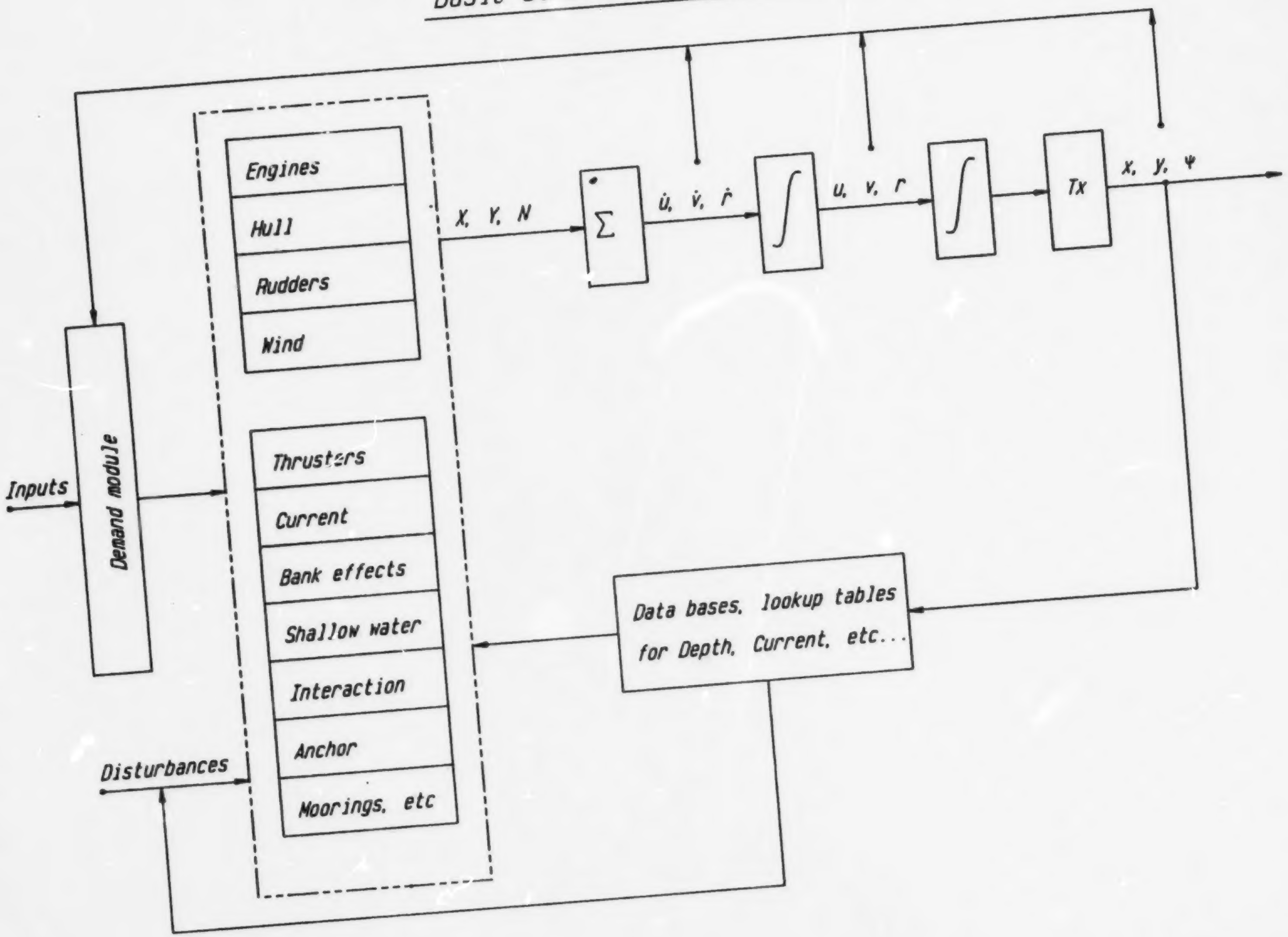
- The icebreaker bow geometry may be idealized by a simple flat-plate wedge.

- The hull side forces are assumed to be distributed over an effective parallel mid-body.

- The total ice resistance in the straight ahead mode is assumed to be concentrated at the ship's bow. (For motion where the ship is at a non-zero drift angle, there will be an additional resistance caused by the frictional forces along the parallel mid-body).

FIGURE 3.1

Basic Structure of a Modular Ship Model


Inputs
Demand module
Engines
Hull
Rudders
Wind
Thrusters
Current
Bank effects
Shallow water
Interaction
Anchor
Moorings, etc
Disturbances
X, Y, N
Σ
u̇, v̇, ṙ
∫
u, v, r
∫
Tx
x, y, Ψ
Data bases, lookup tables for Depth, Current, etc...

- Ice forces are proportional to the volume of ice broken.

- The vessel is assumed to have zero heave, pitch and roll motions, i.e. the model takes into account three-degrees of freedom, the lateral (horizontal) plane. Future developments may be able to relax some of these constraints).

- The presence of ice does not significantly alter the hydrodynamic hull and rudder forces. (Later models are likely to be able to modify the hydrodynamic forces to take account of the presence of the ice).

## 3.3 Methodology

### 3.3.1 Force System

The computation of ice forces and moments are carried out in a separate subroutine in the model which calculates the ship motions. Figure 3.2 shows the inputs and outputs of the procedure. A coefficient File KI holds a number of ship and ice-specific constants. The List of Variables for the ice forces and moments is given in Table 3.1.

The forces and moments to be analyzed are shown in Figure 3.3. They consist of:

- a longitudinal resistance force at the bow, $X_b$, caused by the icebreaking process.

- a lateral force at the bow, $Y_b$, caused by the asymmetrical pattern of icebreaking in a turn.

- a lateral force along the parallel mid-body, $Y_{pm}$, caused by the hull pushing ice aside in turn, if loose, or against edge of track if fixed.

- longitudinal force, $X_{pm}$, caused by the frictional force of the displaced ice along at the parallel mid-body.

- bow and stern moments caused by the transverse forces $Y_b$ and $Y_{pm}$.

- rudder hydrodynamic forces $X_R$ and $Y_R$

- rudder hydrodynamic moment due to $Y_R$

### 3.3.2 Drift Angles

The main algorithm returns an instantaneous value for the drift angle, $\alpha$, at mid-ship. The bow drift angle, $\psi_B$, may be evaluated from geometry referring to Figure 3.4.

$$R = \bar{u}/r \tag{3.1}$$

## TABLE 3.1

## LIST OF VARIABLES

| VARIABLE | MEANING | UNITS |
|---|---|---|
| $d_b$, $d_s$ | Distance of ice forces at bow and stern from CG | m |
| DE | Bow slant distance, [1] | m |
| h | Thickness of ice | m |
| K11 | Dist CG to bow forces | m |
| K12 | Force coefficient $Y_b$ | |
| K13 | Bow force length | m |
| K14 | Cos half bow angle | |
| K15 | Icebreaking force coefficient ($h^2$) | $N/m^2$ |
| K16 | Icebreaking force coefficient (h*4) | $Ns/m^2$ |
| K17 | $Y_{pm}$ force coefficient | - |
| K18 | Ice coefficient of friction | - |
| K19 | Dist CG to side forces | m |
| K20 | Rudder X-force coefficient | |
| K21 | Rudder Y-force coefficient | |
| Lpp | Length between perpendiculars | m |
| $N_b$, $N_s$ | Ice moments at bow and stern | N-m |
| $N_{ice}$ | Total ice moment | N-m |
| r | Yaw rate | rad/s |
| R | Radius of steady turn | m |
| u | Surge velocity of ship | m/s |
| $\bar{u}$ | Total velocity of ship | m/s |
| $X_b$, $X_{pm}$ | Bow and stern forces in surge | N |
| $X_{ice}$ | Total ice force in surge | |
| $Y_b$, $Y_{pm}$ | Bow and stern forces in sway | N |
| $Y_{ice}$ | Total ice force in sway | |
| $\alpha$ | Drift angle at CG | rad |
| $\psi_B$ | Drift angle at bow | rad |
| $\delta$ | Rudder angle | rad |

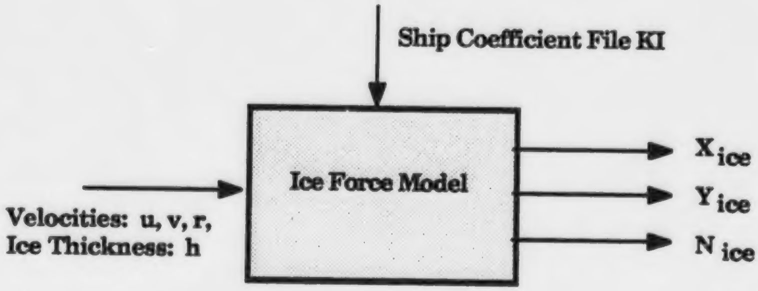

Ship Coefficient File KI
Ice Force Model
Velocities: u, v, r,
Ice Thickness: h
$X_{ice}$
$Y_{ice}$
$N_{ice}$

Figure 3.2 Ice Modelling - Inputs and Outputs

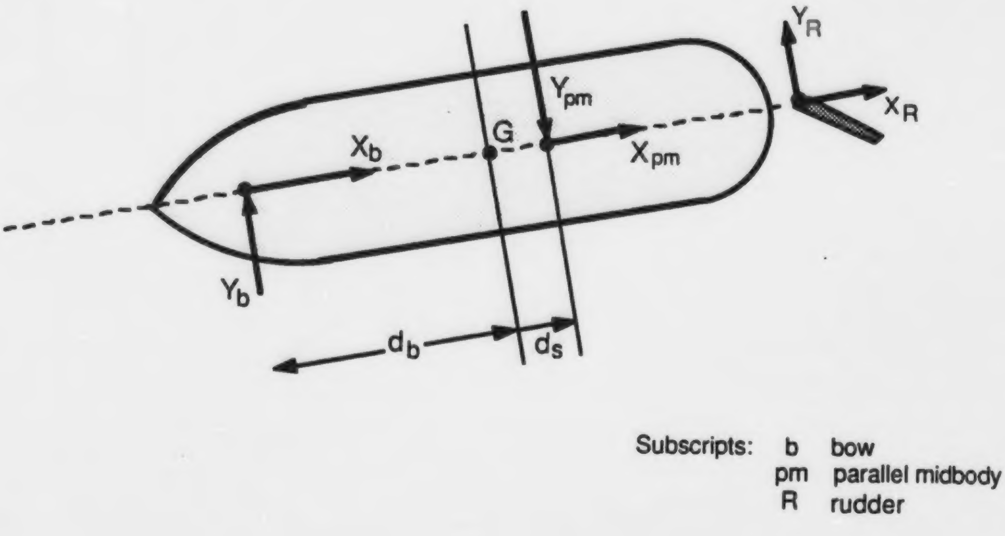

$Y_R$
$X_R$
$Y_{pm}$
G
$X_b$
$X_{pm}$
$Y_b$
$d_b$
$d_s$
Subscripts: b bow
pm parallel midbody
R rudder

Figure 3.3 Forces Acting on Ship Hull

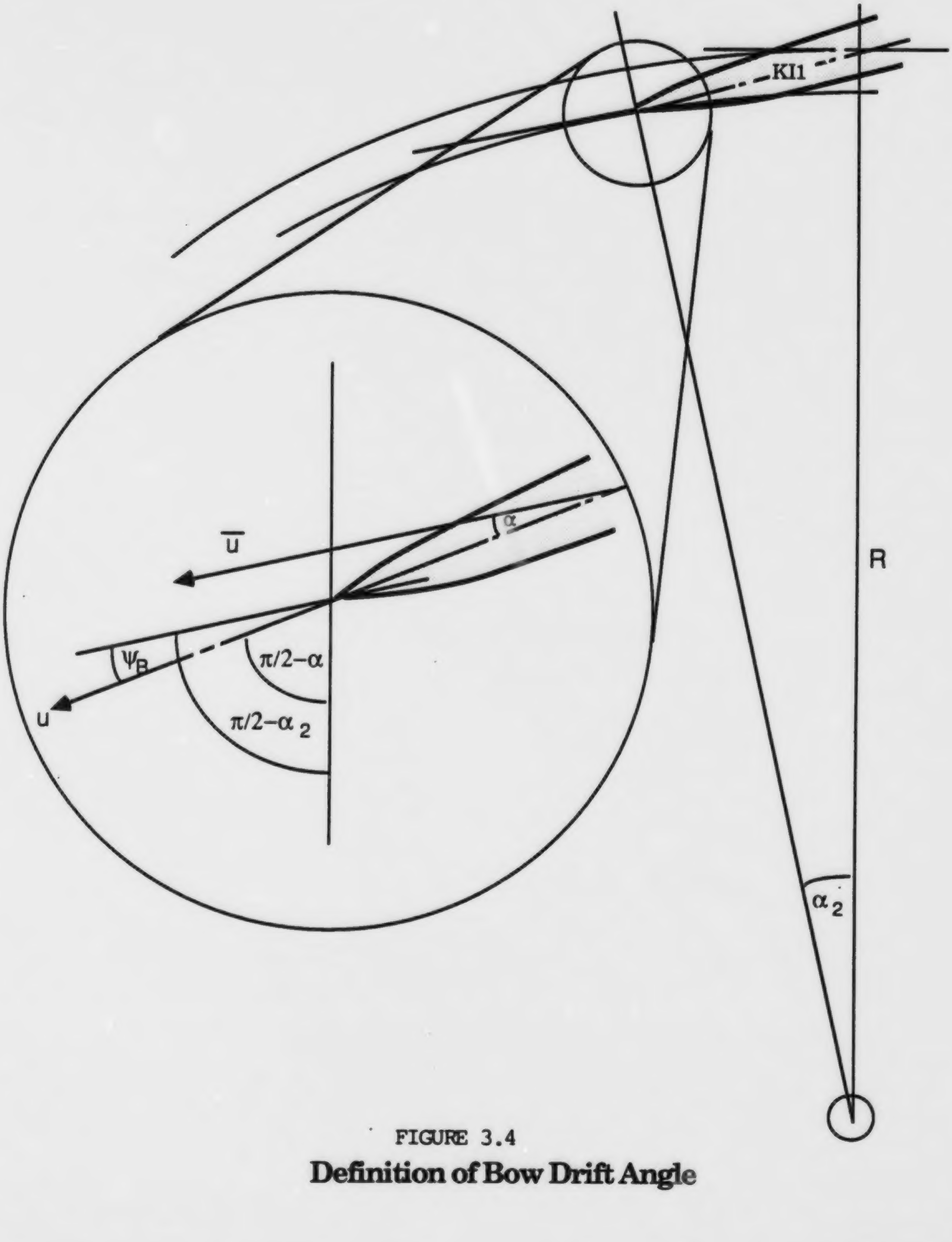

KI1
$\overline{u}$
$\alpha$
R
$\psi_R$
$\pi/2-\alpha$
u
$\pi/2-\alpha_2$
$\alpha_2$

FIGURE 3.4
**Definition of Bow Drift Angle**

For small drift angles, we may write:

$$\alpha_2 = K1l/R$$

The drift angle at the bow is therefore given by:

$$\psi_B = \alpha - \alpha_2$$

Because of the normal sign convention used for the drift angle, (drift angle positive for positive sway velocity), may be evaluated by:

$$\psi_B = \alpha + K1l/R \qquad (3.2)$$

A number of tests have to be incorporated into the code for the evaluation of $\psi_B$, to avoid zero division.

### 3.3.3 Bow Forces and Moments

**Longitudinal force $X_b$:** From Equation 1 of [1], the longitudinal force due to ice may be evaluated by:

$$X_b = - K15 * h^2 - K16 * h * u$$

This expression will however fail at near zero speeds, as a large negative force will remain due to the term in $h^2$, which will tend to reverse the ship. $X_b$ may therefore be obtained from the expressions:

$$X_b = -K15 * h^2 - K16 * h * u, \quad u > 0.01$$

$$X_b = -K16 * h * u \quad u < 0.01 \qquad (3.3)$$

**Lateral force $Y_b$:** For manoeuvring, we are interested only in the difference between the ice forces on either side of the hull. From Equation 20 and 21 of [1], the asymmetric sideforce may be written as:

$$Y_b = K12 * u * K13 * h * 2\sin \psi_B * K14 \qquad (3.4)$$

The direction of $Y_b$ will be determined by the sign of $\psi_B$.

**Bow Moment $N_b$:** This may be found from the equation:

$$N_b = Y_b * K11 \qquad (3.5)$$

### 3.3.4 Mid-body Forces and Moment

Adopting the same principle as used for calculating the bow forces, i.e. that of evaluating the amount of ice disturbed, we may state, as first approximation, referring to Figure 3.5:

$$Y_{pm} = -K17 * \alpha * h * Lpp/2 \qquad (3.6)$$

Assuming the longitudinal force is predominantly due to frictional forces, we may write:

$$X_{pm} = -ABS(ys) * K18 \qquad (3.7)$$

The stern moment is given by:

$$N_{pm} = Ys * K19 \qquad (3.8)$$

### 3.3.5 Rudder Forces and Moment

The hydrodynamic forces on the rudder are written as:

$$X_R = K20 * A_R * \bar{u}_s^{\,2} * \sin \delta_e \qquad (3.9)$$

$$Y_R = K21 * A_R * \bar{u}_s^{\,2} * \cos \delta_e \qquad (3.10)$$

where $\delta_e$ is the effective rudder angle.

Moment due to $Y_R$ then becomes:

$$N_R = Y_R * 1/2\ L_{pp} \qquad (3.11)$$

### 3.3.6 Total Ice Forces and Moment

The total ice forces may now be written as:

$$Xice = Xpm + X_R \qquad (3.12)$$

$$Yice = Y_b + Y_{pm} + Y_R \qquad (3.13)$$

$$Nice = N_b + N_{pm} + N_R \qquad (3.14)$$

## 3.4 Integration of Ice Force Model

The fundamental concept, whereby the forces are related to the amount of ice disturbed, is considered adequate. The usual method of incorporating transient forces and moments into a manoeuvring model is to establish a number of quasi-steady states, at each iteration, and use an appropriate form of time lag to go from one quasi-steady state to another. It is considered that this approach can be used in the present situation. The main area in which the ice forces are considered incomplete is in the manoeuvring condition where the ship is turning in a broken channel. It must be remembered that a ship cannot turn unless it is pointing into the turn. As will be seen in Figure 3.5, when a ship is turning in ice, there will be a very strong restoring moment, as the points of greatest contact shift aft on the outside of the turn and forward on the inside. These two forces will exert a very high stabilizing moment. It is found adequate to calculate the size of the additional normal and frictional forces in a similar manner to that in which the bow ice forces are calculated, i.e. to consider the amount of ice shifted from its previous position. It is likely that there will need to be a few additional changes made to the model in the future, principally in the areas of engine and rudder control. The use of a fully modular model enables this to be done comparatively readily.

In order to facilitate enhancements in the future, it was also found convenient to add the ice forces onto a Force model in exactly the same manner as for other environmental effects. This method has the advantages of rigour, of being able to operate at slow or zero ship speeds, and of being valid at all ice thicknesses. Initial relationships between the instantaneous manoeuvring condition (drift angle or radius of curvature) and the ice forces will be deduced, initially from first principles. The resulting model can then be verified against data from full scale ship trials.

## 3.5 Ship Models for Evaluation

Two icebreaker types were chosen for evaluation purposes - the R- Class, a Canadian class composed of three vessels, and the Polar Class, a U.S. class comprising two vessels. In choosing these ship types four factors were considered:

a) availability of full scale data
b) familiarity of the evaluating personnel (CCG captains) with a class
c) similarities and differences between chosen classes
d) relevance with regards to future investigations

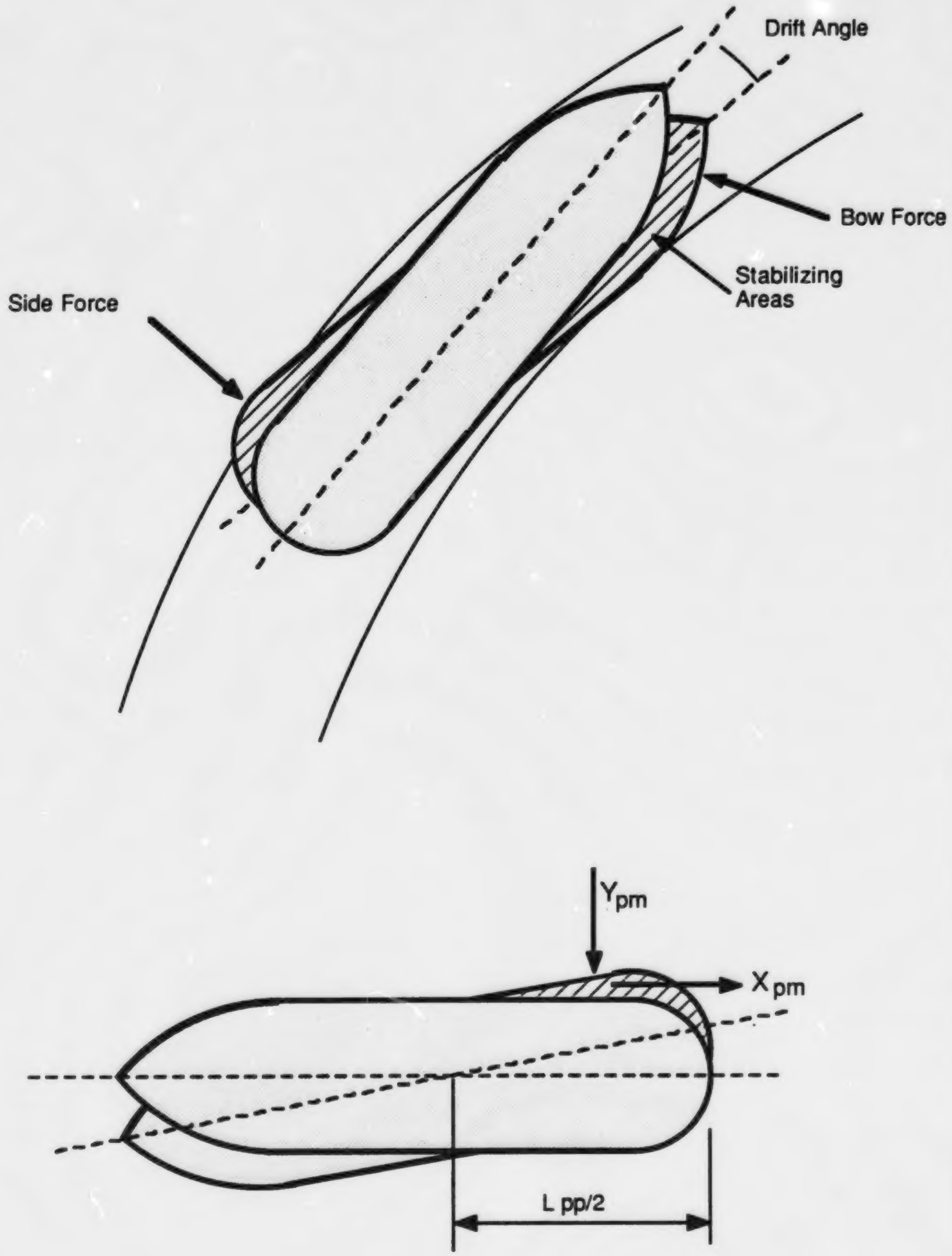

Drift Angle
Bow Force
Stabilizing Areas
Side Force
$Y_{pm}$
$X_{pm}$
L pp/2

**Figure 3.5 Approximation of Side Force and Moment**

From discussions in section 2, it is clear that the fidelity of a model is a direct function of the availability of full scale data and that in constructing a mathematical model, all the information needed to exactly model a ship is almost always unavailable. Gaps in information are bound to exist and must be filled in by estimates of a ship's performance based upon a knowledge of similar ships. Estimates are however only approximate and therefore give rise to inaccuracies in modelling. The two classes chosen are somewhat unique in that they both have a relatively good base of full scale performance and manoeuvring data available.

The choice of the R-Class is highly relevant for TDC purposes. Numerous full scale and model scale tests have been performed upon these ships and they remain a mainstay of the Canadian icebreaking fleet. They are considered to be the premier class of Canadian icebreakers at this time.

The choice of the Polar Class is certainly relevant to this study in that TDC was involved in a five year full scale performance trials program on these vessels along with other U.S. participants, and a large amount of data have been collected and analyzed. These ships are not Canadian but are considered to have the best performance of any non-nuclear powered ships of the western nations. Conceivably a Polar Class model will be useful for comparison purposes when investigations concerning the Polar 8 are conducted.

Two distinct - but relatively similar - classes of ships are desirable. One does not want for example, two classes where the performance of one is simply a scaled up or scaled down version of the other. The choice of the two classes meets this criterion. Both types are fairly close in size but have different icebreaking capabilities. The R-Class is capable of breaking 1 metre thick ice on a sustained basis, while the Polar Class has the capability of breaking ice about 1.6 metres thick using only diesel power. The Polar Class, while being about 50% more powerful is more massive and has a lower power/mass ratio giving them less acceleration and more inertia than the R-Class. In addition, the R-Class is less manoeuvrable than the Polar Class in both open water and in ice. It was therefore felt that the choice of the two classes adequately met the need for two generally similar, yet specifically different performance and manoeuvrability characteristics.

## 3.6 Validation of Ship Models

A ship's mathematical model consists of a set of differential equations with a large number of coefficients. In order to generate the necessary model structure and coefficient fit, a set of data needs to be formulated. This data consists of two parts - static data, normally obtainable from lines plans and ship particulars, and dynamic or trials data, typically obtained from acceptance and/or dedicated trials.

The following particulars are needed to build a ship model:

| | |
|---|---|
| Displacement | tonnes |
| Length between perpendiculars | m |
| Breadth | m |
| Draft - Forward | m |
| Draft - Aft | m |
| Moulded depth | m |
| Block Coefficient | |
| Number, type and engine rating | kW |
| Number of shafts | |
| Direction of rotation of screws | Inboard/Outboard |
| Maximum shaft speed | rpm |
| Type of Propellers | Fixed or CPP |
| Number and position of rudders | |
| Area of each rudder | $m^2$ |
| Maximum rudder angle | deg |
| Time for rudder, hard port to hard starboard | sec |
| Maximum ship speed | Kt |

The following dynamic information is necessary for a ship model:

| | |
|---|---|
| Inertia trial | |
| - Initial speed | Kt |
| - Final speed | Kt |
| - Time to one third final speed | sec |
| Acceleration trial | |
| - Initial speed | Kt |
| - Final speed | Kt |
| - Time to two thirds final speed | sec |
| Turning circle | |
| - Rudder angle | deg |
| - Initial speed | Kt |
| - Steady speed | Kt |
| - Steady turn rate | deg/min |
| - Final diameter | m |

Given the above information, a set of initial ship coefficients can be calculated and tested. A basic preliminary ship handling test is first performed to ascertain if the performance and manoeuvrability is generally correct. One often finds that changes to coefficient values needs to be made to get the model to 'behave'. Once a model is functional a full series of validation runs need to be made, typically with further changes to calculated coefficients, to ensure that the dynamic behaviour is correct. A straightforward calculation of the effect of changing a coefficient value unfortunately cannot be made due to the complex interrelated nature of the coefficients. It is therefore necessary to iteratively change coefficients and then test a model. Eventually the measured performance values are deemed to be close enough to the target values and the model is ready for its final testing which needs to be done by a qualified mariner. The mariner puts the model through the entire range of manoeuvres and basically verifies the validity of the model. If changes are necessary, the mariner must re-verify the performance checks previously done. Tables 3.2 and 3.3 present target and obtained values of ship performance for the R-Class and Polar Class respectively.

**TABLE 3.2 R-CLASS - TARGET AND OBTAINED PERFORMANCE PARAMETERS**

| PARAMETER | TARGET VALUE | OBTAINED VALUE |
|---|---|---|
| Maximum Shaft Speed | 184 rpm | 184 rpm |
| Maximum Rudder Angle | 37° | 37° |
| Maximum Ship Speed - Open Water | 8.5 m/s | 8.4 m/s |
| - 50 cm Ice | 5.4 m/s | 4.9 m/s |
| - 100 cm Ice | 1.0 m/s | 1.0 m/s |
| Turning Circle Diameter - O/W | 370 m (est) | 466 m |
| - 50 cm Ice | 1050 m (est) | 916 m |
| - 100 cm Ice | 3200 m (est) | 2842 m |
| Rate of Turn (Rudder Only) | | |
| - O/W | 1.9 deg/sec (est) | 1.33 deg/sec |
| - 50 cm Ice | 0.5 deg/sec (est) | 0.48 deg/sec |
| -100 cm Ice | 0.1 deg/sec (est) | 0.02 deg/sec |
| Time 0 to 2/3 Max Speed - O/W | 57 sec (est) | 69 sec |
| Time Max Spd to 1/3 Max - O/W | 170 sec (est) | 135 sec |
| Time Crash Stop - O/W | 70 sec (est) | 63 sec |

**TABLE 3.3 POLAR CLASS - TARGET AND OBTAINED PERFORMANCE PARAMETERS**

| PARAMETER | TARGET VALUE | OBTAINED VALUE |
|---|---|---|
| Maximum Shaft Speed | 120 rpm | 120 rpm |
| Maximum Rudder Angle | 35° | 35° |
| Maximum Ship Speed - Open Water | 8.0 m/s | 8.0 m/s |
| - 50 cm Ice | 5.4 m/s | 4.9 m/s |
| - 100 cm Ice | 1.0 m/s | 1.0 m/s |
| Turning Circle Diameter - O/W | 400 m (est) | 524 m |
| - 80 cm Ice | 1350 m (est) | 1582 m |
| - 160 cm Ice | 3750 m (est) | 4224 m |
| Rate of Turn (Rudder Only) | | |
| - O/W | 1.5 deg/sec (est) | 0.98 deg/sec |
| - 80 cm Ice | 0.5 deg/sec (est) | 0.25 deg/sec |
| -160 cm Ice | 0.1 deg/sec (est) | 0.03 deg/sec |
| Time 0 to 2/3 Max Speed - O/W | 70 sec (est) | 63 sec |
| Time Max Spd to 1/3 Max - O/W | 200 sec (est) | 104 sec |
| Time Crash Stop - O/W | 70 sec (est) | 70 sec |

# 4. TECHNICAL MODIFICATIONS TO CABINS

A number of technical modifications to CABINS were necessary to fulfill the requirements of this contract. These can be divided into five general areas:

1) design and implementation of a new gaming area and creation of the associated water depth, two-dimensional and three-dimensional visual data bases.

2) general system changes to facilitate the selection of a specific gaming area, ship model and ice thickness data base.

3) specific changes made to produce and use ice thickness data bases and to include ice forces in the force model algorithm.

4) modification of the radar display to show an ice edge when needed and to show a ship track for both the target and own vessels.

5) modifications to the visual generation program to enhance the presentation of a target vessel when it is nearby.

## 4.1 Gaming Area Creation

A generalized exercise area was agreed upon by the two captains after discussions with CABINS personnel. A two-dimensional data base was then created, based upon the rough outline illustrated in Figure 4.1. The data base, measuring 6000 m x 5000 m contains X, Y coordinate information regarding the shorelines and shorelights. This information is used to create images generated by the radar, plotter and instructor computers.

Next a water depth data base was constructed based upon the above coordinate system. The gaming area was divided into 480 squares, measuring 250 m to a side, with a depth value assigned to the center point of each square. The water depth at any location within the gaming area is calculated by linear interpolation between the nearest central grid points in both the X and Y directions. Figure 4.2 presents the depth values at these center points with values of 0, on land, omitted for clarity.

Lastly, a three-dimensional data base of stationary lights (shorelights, buoys, lighthouses, etc.) is created. This data base contains X, Y and Z coordinate data along with colour, flashing characteristics, and visibility information.

FIGURE 4.1

LAYOUT OF THE EXERCISE AREA

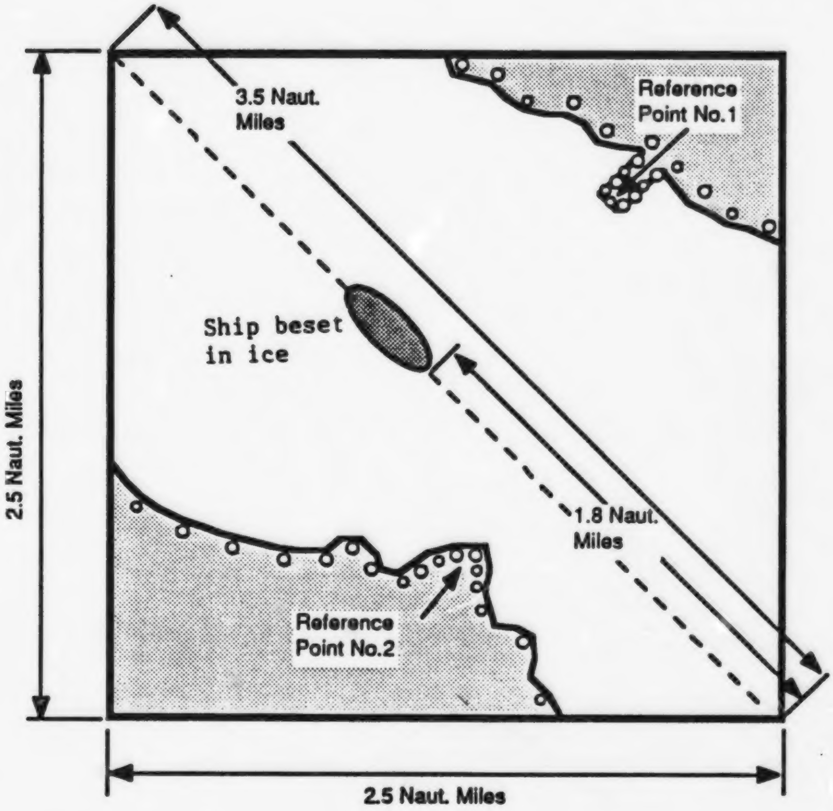
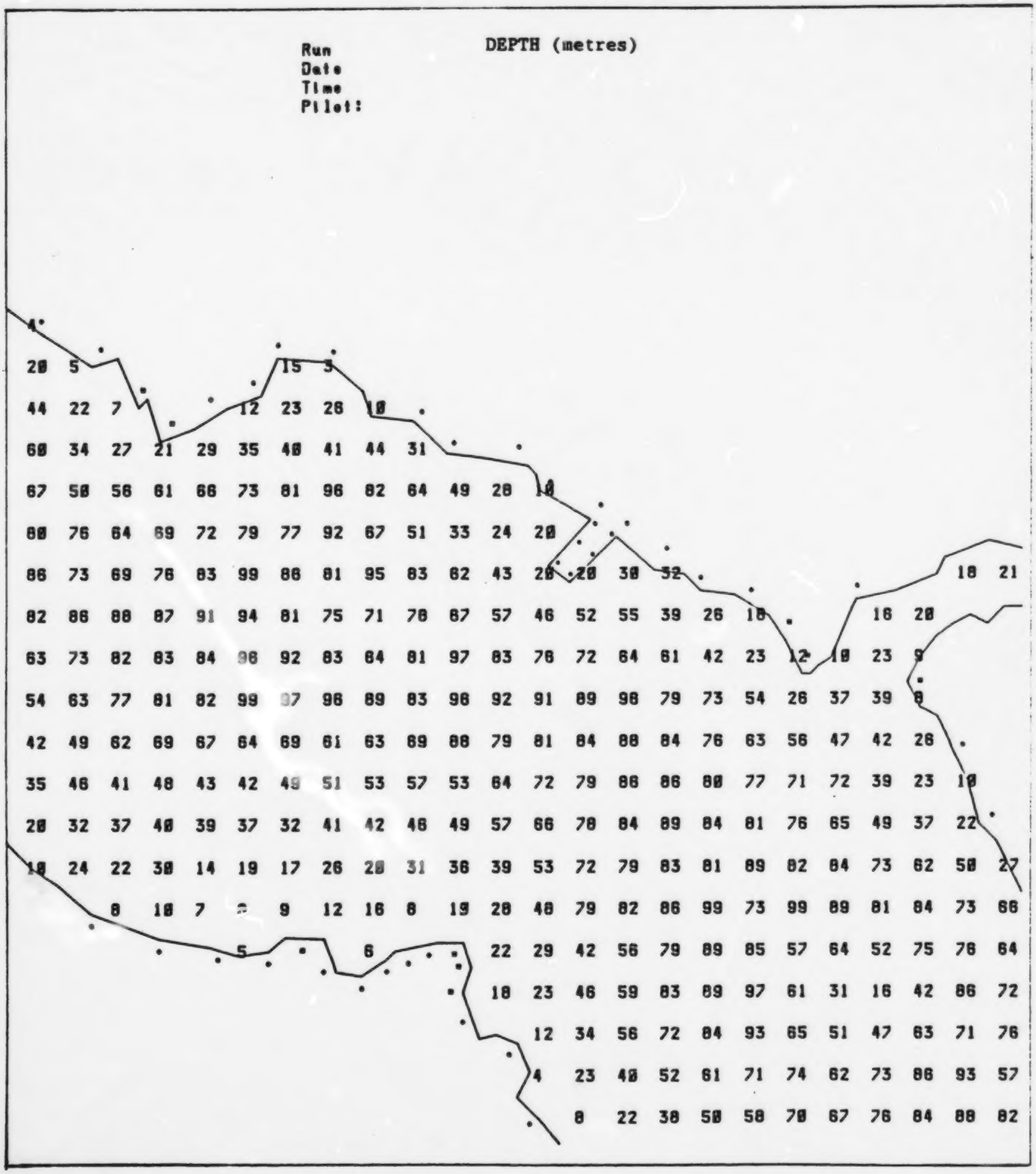

3.5 Naut. Miles
Reference Point No.1
Ship beset in ice
2.5 Naut. Miles
1.8 Naut. Miles
Reference Point No.2
2.5 Naut. Miles

FIGURE 4.2

TYPICAL DEPTH DATA BASE FOR EXERCISE AREA


Run
Date
Time
Pilot:
DEPTH (metres)
4
20 5 15 3
44 22 7 12 23 28 10
60 34 27 21 29 35 40 41 44 31
67 50 56 61 66 73 81 96 82 64 49 28 10
80 76 64 69 72 79 77 92 67 51 33 24 20
86 73 69 76 83 99 86 81 95 83 62 43 28 20 30 32 18 21
82 86 88 87 91 94 81 75 71 78 87 57 46 52 55 39 26 18 18 20
63 73 82 83 84 96 92 83 64 81 97 83 78 72 64 61 42 23 12 18 23 9
54 63 77 81 82 99 97 96 89 83 96 92 91 89 98 79 73 54 26 37 39 8
42 49 62 69 67 64 69 61 63 69 88 79 81 84 88 84 76 63 56 47 42 26
35 46 41 48 43 42 49 51 53 57 53 64 72 79 86 86 80 77 71 72 39 23 10
20 32 37 40 39 37 32 41 42 46 49 57 66 78 84 89 84 81 76 65 49 37 22
10 24 22 30 14 19 17 26 20 31 36 39 53 72 79 83 81 89 82 84 73 62 50 27
8 10 7 8 9 12 16 8 19 28 48 79 82 86 99 73 99 89 81 84 73 66
5 6 22 29 42 56 79 89 85 57 64 52 75 78 64
18 23 46 59 83 89 97 61 31 16 42 86 72
12 34 56 72 84 93 65 51 47 63 71 76
4 23 40 52 61 71 74 62 73 86 93 57
8 22 38 50 58 70 67 76 84 88 82

## 4.2 General System Changes

A host of minor system changes were necessary to accommodate the additional port, ship, and ice thickness data bases. The specifics of these changes are not particularly relevant to the discussion at hand, but a general overview is helpful. Basically the modifications were two-fold. First, the startup procedure was changed to allow the selection of the additional gaming area and two new ship models. As well, an easy menu driven selection of a particular ice thickness data base was provided for. Second, the information sent between the various computing nodes was increased to include the additional ice relevant data, and the receiving programs were accordingly changed.

## 4.3 Specific Changes Made to Include Ice Forces

Changes to the program that were necessary to accommodate the ice forces algorithm were not extensive due to the existing structure of the program. To calculate the instantaneous velocities in surge, sway and yaw, the total force in those directions must be known. If one takes a simplified approach, and assumes that the total force is the sum of the ice force and hydrodynamic force, it is then a simple calculation and easily implemented.

Twelve individual ice thickness data bases, six per ship, were constructed for the exercise. These data bases were basically structured the same as the water depth data base, in a two-dimensional grid pattern (see section 4.1). To ease data base creation, a program was written that allowed the user to input the average thickness, variability and grid base. The program then calculated and stored the ice thickness at each grid point for later use during an exercise. Table 4.1 lists the ice thickness data bases used for the exercise, and a typical example of the ice thickness profile is shown in Figure 4.3. A complete listing of all the variable thickness ice data bases can be found in Appendix A.

The grid sizes chosen were more than adequate for ahead manoeuvring in level ice. Problems were found to occur however, in attempting to model the broken channel created by a ship. These problems made it necessary to alter the ice thickness algorithm from a simple one using linear interpolation to a much more complicated one.

To approximately simulate a broken channel, the ice thickness within a grid was reduced by 25% when a ship passed through it. Thereafter, if a ship either backed up through a grid, or crossed it in a manoeuver, the ship would find itself in effect operating in thinner ice and hence accelerate. It was necessary of course to ensure that the thickness be reduced only once and that the linear interpolation routine only use grid points in the direction of travel. This ensured that the calculated thickness was not influenced by a reduced value astern unless the ship was actually travelling astern.

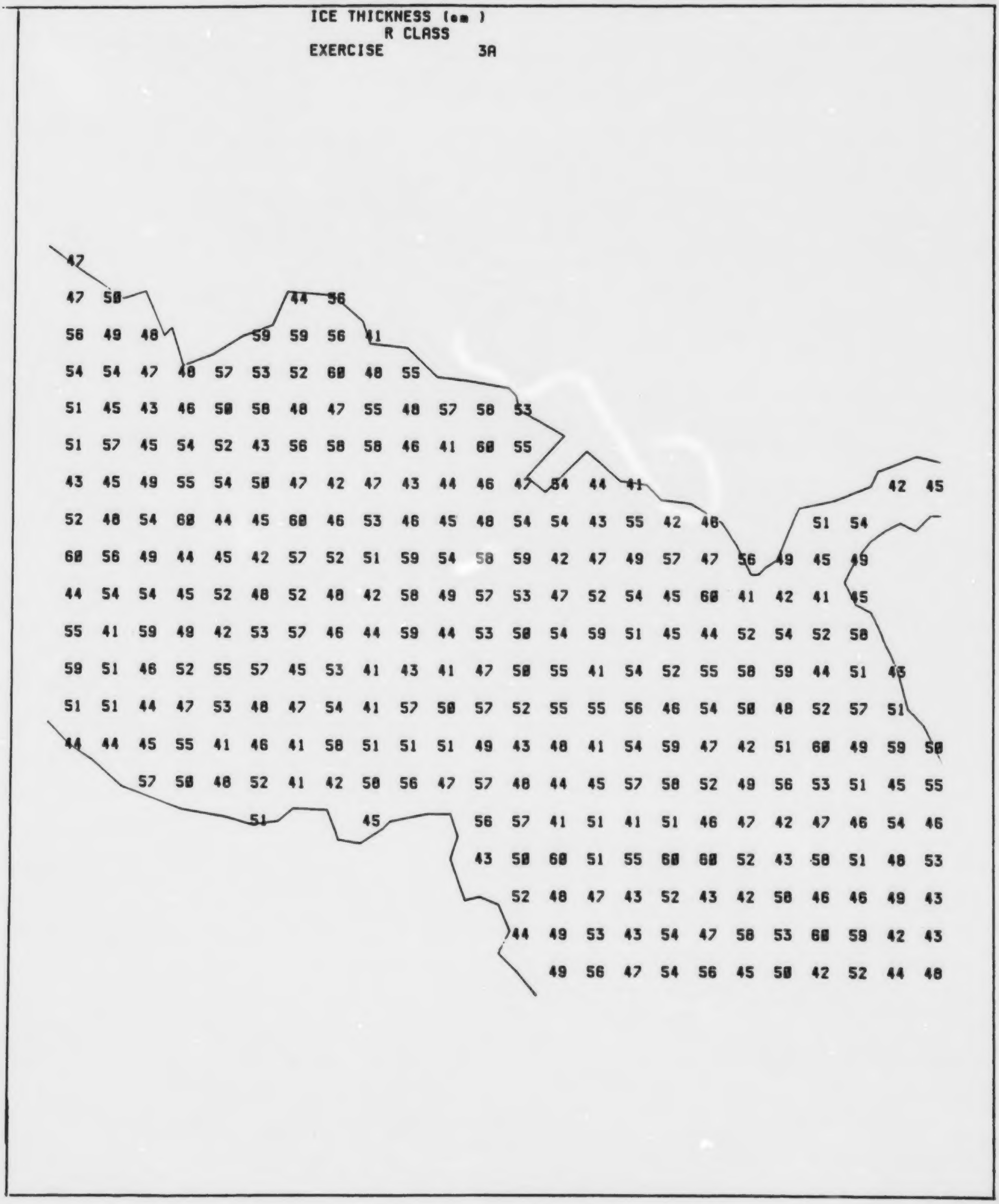
## TABLE 4.1

## GAMING AREA PARAMETERS

| | R-Class<br>ICE THICKNESS | GRID SIZE | Polar Class<br>ICE THICKNESS | GRID SIZE |
|---|---|---|---|---|
| 1 | 0 / 0.5 m | 250 m x 250 m | 0 / 0.8 m | 250 m x 250 m |
| 2A | 0.5 m | | 0.8 m | |
| B | 1.0 m | | 1.6 m | |
| 3A | 0.5 ± 0.1 m | | 0.8 ± 0.16 m | |
| B | 1.0 ± 0.2 m | | 1.6 ± 0.32 m | |
| 4 | 0.5 ± 0.1 | 125 m x 125 m | 0.8 ± 0.16 | 125 m x 125 m |

FIGURE 4.3

TYPICAL ICE THICKNESS DATA BASE FOR EXERCISE AREA



```
              ICE THICKNESS (cm )
                      R CLASS
              EXERCISE            3A

47
47  50                  44  56
56  49  48          59  59  56  41
54  54  47  48  57  53  52  60  48  55
51  45  43  46  50  58  48  47  55  48  57  58  53
51  57  45  54  52  43  56  58  58  46  41  60  55
43  45  49  55  54  50  47  42  47  43  44  46  47  54  44  41                          42  45
52  48  54  60  44  45  60  46  53  46  45  48  54  54  43  55  42  48          51  54
60  56  49  44  45  42  57  52  51  59  54  58  59  42  47  49  57  47  56  49  45  49
44  54  54  45  52  48  52  48  42  58  49  57  53  47  52  54  45  60  41  42  41  45
55  41  59  49  42  53  57  46  44  59  44  53  50  54  59  51  45  44  52  54  52  50
59  51  46  52  55  57  45  53  41  43  41  47  50  55  41  54  52  55  58  59  44  51  43
51  51  44  47  53  48  47  54  41  57  50  57  52  55  55  56  46  54  50  48  52  57  51
44  44  45  55  41  46  41  58  51  51  51  49  43  48  41  54  59  47  42  51  60  49  59  50
        57  50  48  52  41  42  50  56  47  57  48  44  45  57  58  52  49  56  53  51  45  55
                    51          45          56  57  41  51  41  51  46  47  42  47  46  54  46
                                            43  50  60  51  55  60  60  52  43  50  51  48  53
                                                52  48  47  43  52  43  42  50  46  46  49  43
                                                44  49  53  43  54  47  58  53  60  59  42  43
                                                    49  56  47  54  56  45  50  42  52  44  48
```

## 4.4 Modification of Radar Display

Some modification to the radar display was necessary in order to provide a more realistic in-ice display. Specifically, a ship track and/or an ice edge was needed. To produce an ice edge and ship track for the target ship two versions of the visual two-dimensional data base (section 4.1) were produced. The lines representing the ice edge and target ship track were drawn in the same fashion as the coastlines. To understand how the 'own' ship track was generated, a brief description of the program is necessary.

The coastline data base is loaded into computer memory prior to the start of a run. The coastline is drawn as a series of line segments connecting two or more X, Y coordinates. During program execution, the radar computer receives position and heading data for the own ship and any target ships. With each loop through the program the coastline segments and target ships are re-drawn in memory with the origin shifted so that the own ship is always in the center. The visual display is then placed on the screen only when the drawing process is complete. This new visual display is then held on the screen until the program completes another loop and has a new display to be shown on the screen.

The changes made to include an open ship track were relatively straight forward. The track was drawn as if it were just another coastline segment. This was done by continually adding to the coastline data base to include the new position data received by the radar computer. The amount of ship track data that could be added was a function of the amount of computer memory available and the amount already used to store the coastline data. It was found that up to 50 minutes of data could be stored before encountering difficulty.

## 4.5 Changes to the Visual Generation Program

The scenario chosen, breaking out a beset target ship, made it necessary to modify the visual generation program for better target ship definition. These modifications helped to alleviate somewhat the drawbacks of nocturnal simulation. To better define the target ship, a large number of lights were positioned along the main deck perimeter and on the superstructure. Unfortunately, it was not possible to produce a silhouette of the vessel. To do so would have slowed the program unacceptably, resulting in an uneven, jerky motion to the display. Changes to the program were made to accommodate this increased number of lights, and to allow more freedom in the definition of their characteristics (colour and intensity).

## 5. OPERATIONAL EVALUATION

### 5.1 Involvement of CCG Captains

It is clear from section 3 that the development of the mathematical model of ship performance is carried out independent of any operator input and is purely based on sound engineering principles supported by empirical evidence.

Clearly an operational assessment of the accuracy of a model is dependent upon one's real life experience. It was felt that a fair basis for judgement of validity was one in which two captains were operating the simulator with ship models that were reasonably close in performance to vessels they have piloted. Captain Pat Toomey of the Canadian Coast Guard was the skipper of the CCGS PIERRE RADISSON, an R-Class vessel for a number of years. He has also been onboard the USCGC POLAR SEA, a Polar Class vessel, during icebreaking operations. He has been an officer aboard various Canadian icebreakers since the 1960's. Captain Eric Hann of the Canadian Coast Guard has as well vast icebreaking experience. He has commanded the CCGS JOHN A. MACDONALD and the CCGS LABRADOR, both of which are reasonably close to the vessel types chosen for this study. Based upon the experience of both captains it was felt that the two chosen ship types were highly valid for evaluation purposes.

### 5.2 Development of Scenarios

The two captains performed a total of 24 exercises in four days. Each captain performed twelve exercises and used the R-class ship model in the first six exercises and the Polar Class Ship model in the second six exercises. Each of the six exercises was carried out in a different gaming area, namely:

Exercise 1: in half ice/half water
Exercise 2 (A&B): in level ice
Exercise 3 (A&B): in varying ice thickness
Exercise 4: in varying ice thickness with different grid size

Before running the six exercises with each model, the captains were briefed in full detail about:

1) The general particulars of each ship (LOA, Breadth, etc.);
2) Manoeuvring Data (Turning Circle, Tactical Diameter, etc.);
3) Particulars of the exercises, the scenario and the gaming area.

The duration of each exercise was about 30-35 minutes and then the captains took about 5-10 minutes to complete a validation form. At the end of the day the captains completed a final evaluation form indicating their opinions and recommendations on how the simulations can be improved to be more realistic. The details of the exercises and the format of the evaluation forms are explained below. Each captain was at FTL for two days to carry out a total of 12 exercises.

**Exercise No. 1** **Half Open Water/Half Ice**

During this exercise the ship was at all times in the open water area. The captains performed any series of manoeuvres as they saw necessary to give them a feel for the ship's manoeuvrability in confined waters and in moving from open water to ice covered water. Manoeuvres such as a turning circle, stopping distance, crash stop distance and acceleration or deceleration rate were performed. When using the R-class ship model (the first model to be used) the captains were able to compare between their experience onboard the icebreaker and the simulation from an operational view point. On the other hand, when using the Polar-class ship model, they were able to evaluate the simulator, as a training tool that may be used to gain experience on an unfamiliar type of ship.

In the following five exercises the captains manoeuvred their ship in order to free a beset ship in ice.

**Exercise No. 2 (A&B)**

This exercise was carried out in two thicknesses of level homogeneous ice. For the R-Class, in exercise 2A the ice thickness was 0.5 metres and in exercise 2B, it was one metre. For the Polar class, in exercise 2A the ice thickness was 0.8 metres and in exercise 2B it was 1.6 metres.

**Exercise No. 3 (A&B)**

This exercise was carried out in varying ice thicknesses. The ice thickness was averaged in exercise 3A and 3B as in exercise 2A and 2B respectively, but in exercises 3A & B, the ice thickness varied randomly throughout the gaming area in the range ±20% of the average ice thickness.

The gaming areas through exercises No. 1, No. 2A & B and No. 3 A&B were divided into cells that were 250 metres long by 250 metres wide. The ice thickness at any point within the gaming area was interpolated from the thickness values of the four nearest adjacent cells to the ship's position.

**Exercise No. 4**

This exercise was carried out in varying ice thicknesses with an average thickness as in exercise No. 3A for each class. The cells length and width was represented 125 metres.

As mentioned above, after finishing each exercise, the captains completed a validation form, a sample of which is shown below. The validation forms are the basis of validating the ship's math model from the operators point of view.

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. The rate of acceleration | | | | | | | | | | | |
| | Ahead | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | Astern | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 2. The rate of deceleration | | | | | | | | | | | |
| | Ahead | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | Astern | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 3. The rate of turn (as a result of the rudder's angle) | | | | | | | | | | | |
| | To Starboard | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | To Port | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 4. The rate of turn (as a result of using the propellers one ahead and one astern. | | | | | | | | | | | |
| | To Starboard | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | To Port | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 5. The rate of turn (as a result of using the propellers and the rudder). | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

At the end of each exercise, the graphical output of the exercise, the print out of the different manoeuvres occurring during the exercise and the validation form of each exercise were put together and given a number. The similar exercises of the two captains were attached together.

At the end of all exercises each captain provided his own comments about the simulation process in general by completing a final evaluation form, a sample of which is shown opposite.

The exercise graphic plots and print-outs, the validation forms plus the final evaluation form were the basis for preparing the final validation statement as well as the perceptual fidelity recommendations.

## FINAL EVALUATION FORM

### A. BRIDGE INSTRUMENTS

Please rank the following items from 1 to 10 to indicate how realistic they are. The higher the rank the more realistic the item (circle the right number):

1. Navigation Lights 1 2 3 4 5 6 7 8 9 10

2. Communication
   - External (VHF) 1 2 3 4 5 6 7 8 9 10
   - Internal (telephone)

3. Rudder angle indicator
   - Wheel Indicator (Helm) 1 2 3 4 5 6 7 8 9 10
   - Actual Rudder Position (Overhead) 1 2 3 4 5 6 7 8 9 10

4. The rudder response time (the time between moving the wheel to the desired position and when the rudder is actually there). 1 2 3 4 5 6 7 8 9 10

5. The engine response time (the time between setting the throttles at the desired speed and when the RPM indicators indicate the correct reading). 1 2 3 4 5 6 7 8 9 10

6. Ship's head
   - Heading Indicator 1 2 3 4 5 6 7 8 9 10
   - Steering Gyro Repeater 1 2 3 4 5 6 7 8 9 10

7. Radar Simulated Image (general) 1 2 3 4 5 6 7 8 9 10

8. Speed Indicator 1 2 3 4 5 6 7 8 9 10

9. Depth Indicator 1 2 3 4 5 6 7 8 9 10

10. RPM Indicator 1 2 3 4 5 6 7 8 9 10

11. Propeller Throttles 1 2 3 4 5 6 7 8 9 10

12. Chart Room & Charts 1 2 3 4 5 6 7 8 9 10

13. Layout of the Bridge Instruments 1 2 3 4 5 6 7 8 9 10

## B. EVALUATING THE GAMING AREA

Please indicate the level of adequacy of the items below to the Simulation process. The higher the number the more adequate the item: (Please circle the level of adequacy).

### B.1 'Out of the window' visuals:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1 | The number of reference points included as a part of the shoreline. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1.2 | The number of lights shown in the nocturnal view: | | | | | | | | | | |
| | Lights in General | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | Lights Indicating the Reference Points | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | The number of lights indicating the target ship. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

### B.2 Radar Simulated Image

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.1 | Detail of Shorelines | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 2.2 | Target Ship Picture | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 2.3 | Details of ship's own track in ice | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 2.4 | Obtainable information offering safe navigation (Range and bearing, etc.) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

### B.3 Radar Ranges (Please Circle the Appropriate Radar Range)

| | | | | |
|---|---|---|---|---|
| The most frequent range used | 0.75 | 1.5 | 3.0 | 6.0 |
| The smallest range used | 0.75 | 1.5 | 3.0 | 6.0 |
| The largest range used | 3.0 | 6.0 | 12.0 | 24.0 |

## C. MATHEMATICAL SHIP'S MODEL

Please comment on the following:

1. Representation of ship's manoeuvrability on a simulator:

2. Gaining experience by operating a ship model on the simulator when you don't have any experience of operating such a ship in the real life (Polar Class ship model).

## D. VISUALS

1. Was the nocturnal view sufficient for the simulation of manoeuvring in ice? How satisfactory/unsatisfactory? and Why?

2. Do you think that having the daylight view will improve the value of research and/or training?

3. Are there any additional features that can be added to the Simulator to make it more realistic without having daylight view? (Sound, Vibration, motion, etc.).

4. Was the configuration of the lights of the target ship appropriate in simulating the real life situation? Do you prefer a better presentation of the target ship? Please specify.

## E. SCENARIOS

1. Were they complex or simple? Why? (Please write your own suggestions).

2. What can be added as a part of the scenario to make it more realistic?

3. Comment on the feeling of ice restricting the manoeuvrability of ships presented on the simulator?

## F. GENERAL COMMENTS

Write in this part your opinion of the whole process of simulating ship handling in ice and how it can be modified depending on your experience in using the Simulator in comparison to the real life situations.

## 5.3 Perceptual Validation

Capt. Pat Toomey and Capt. Eric Hann of the Canadian Coast Guard, who are experienced icebreaker captains, tested the ship-handling models of the R-Class and the Polar Class vessels on CABINS over a period of four days. Each captain performed a total of twelve exercises, six of which using the R-Class model and the other six using the Polar Class model. The exercises were performed as explained in 5.2.

At the end of every exercise each captain completed a preliminary model validation form. A hard copy of every exercise has been obtained from the plotter. All the hard copies and their corresponding validation forms are also included in Appendix A. Some of the exercises have been recorded on cassette tapes and are submitted separately.

## 5.4 Program Evaluation

The complete results of system evaluation are summarized in Tables 5.1 and 5.2. Items in both these tables are discussed in the following sub-sections, based on the captain's verbal comments recorded on tape.

### A) Models

The mathematical model validation forms which were completed at the end of every exercise were used to determine the level of realism of the simulation process. A higher percentage indicates a higher level of realism. The end results for each mathematical model performance in each captain's opinion are shown in details in Table 5.1. By considering the evaluation of both captains, Table 5.1 shows that the R-class math model was 68.5% realistic and the Polar Class math model was 69% realistic.

### B) Fidelity

Each captain after performing twelve exercises, completed an evaluation form in which they judged the bridge instruments, 'out of window' visuals and the radar simulated image. They were also allowed to express their comments on the math models, the visuals, the scenarios and some general comments. The two evaluation forms are included in Appendix B.

Table 5.2 shows in detail how the captains determined the degree of realism of each of the bridge instruments, and indicated the level of adequacy of 'out of window' visuals and the radar simulated image. As a whole the average end results between the two captains showed that the above mentioned items were 76% realistic.

TABLE 5.1

AVERAGE RESULTS OF ALL EXERCISES
INDICATED AS A PERCENTAGE OF COMPLETE REALISM

| | | Capt.E.Hann | | Capt.P.Toomey | |
|---|---|---|---|---|---|
| | | R-Class | Polar Class | R-Class | Polar Class |
| 1. The rate of acceleration | | | | | |
| | Ahead | 80% | 80% | 57% | 65% |
| | Astern | 80% | 72% | 70% | 66% |
| 2. The rate of deceleration | | | | | |
| | Ahead | 80% | 72% | 58% | 55% |
| | Astern | 80% | 72% | 60% | 62% |
| 3. The rate of turn (as a result of the rudder's angle) | | | | | |
| | To Starboard | 80% | 80% | 73% | 76% |
| | To Port | 80% | 80% | 73% | 77% |
| 4. The rate of turn (as a result of using the propellers one ahead and one astern. | | | | | |
| | To Starboard | 58% | 58% | 55% | 72% |
| | To Port | 58% | 58% | 60% | 73% |
| 5. The rate of turn (as a result of using the propellers and the rudder). | | 58% | 58% | 67% | 70% |
| 6. The mathematical model as a whole. | | 73% | 70% | 64% | 68% |
| **Average evaluation of the Two Captains** | | | | | |
| | • **R-Class** | 68.5% | | | |
| | • **Polar Class** | | 69% | | |

## TABLE 5.2
## FINAL EVALUATION FORM

| | CAPT.E. HANN | CAPT. P. TOOMEY | AVERAGE |
|---|---|---|---|
| **A. BRIDGE INSTRUMENTS** | | | |
| 1. Navigation Lights | 80% | 80% | 80% |
| 2. Communication<br>- External (VHF)<br>- Internal (telephone) | 90% | 90% | 90% |
| 3. Rudder angle indicator | | | |
| - Wheel Indicator (Helm) | 90% | 90% | 90% |
| - Actual Rudder Position (Overhead) | 90% | 90% | 90% |
| 4. The rudder response time (the time between moving the wheel to the desired position and when the rudder is actually there). | 80% | 90% | 85% |
| 5. The engine response time (the time between setting the throttles at the desired speed and when the RPM indicators indicate the correct reading). | 80% | 40% | 60% |
| 6. Ship's head | | | |
| - Heading Indicator | 80% | 90% | 85% |
| - Steering Gyro Repeater | 80% | - | 80% |
| 7. Radar Simulated Image (general) | 70% | 20% | 45% |
| 8. Speed Indicator | 80% | 70% | 75% |
| 9. Depth Indicator | 80% | 80% | 80% |
| 10. RPM Indicator | 80% | 90% | 85% |
| 11. Propeller Throttles | 80% | 90% | 85% |
| 12. Chart Room & Charts | 80% | 90% | 85% |
| 13. Layout of the Bridge Instruments | 80% | 70% | 75% |

TABLE 5.2 (CONTINUED)

| | | CAPT.E. HANN | CAPT. P. TOOMEY | AVERAGE |
|---|---|---|---|---|
| B.1 | 'Out of the window' visuals: | | | |
| 1.1 | The number of reference points included as a part of the shoreline. | 80% | 70% | 75% |
| 1.2 | The number of lights shown in the nocturnal view: | | | |
| | Lights in General | 80% | 70% | 75% |
| | Lights Indicating the Reference Points | 80% | 60% | 70% |
| | The number of lights indicating the target ship. | 80% | 50% | 65% |
| B.2 | Radar Simulated Image | | | |
| 2.1 | Detail of Shorelines | 90% | 70% | 80% |
| 2.2 | Target Ship Picture | 70% | 20% | 45% |
| 2.3 | Details of ship's own track in ice | 90% | 40% | 65% |
| 2.4 | Obtainable information offering safe navigation (Range and bearing, etc.) | 90% | 60% | 75% |
| | **TOTAL AVERAGE** | **82%** | **60%** | **76%** |

The Captains comments about the different items can be summarized as follows:

## C) MATHEMATICAL SHIP'S MODEL

In evaluating the ship performance both Captains emphasized the importance of simulating the broken channel behind own ship which has a significant influence on the Captain's decisions and choices of the various techniques used in freeing a beset ship.

Capt. Toomey indicated that the ship's model is not realistic while turning. In a real life situation when the ship loses its headway in ice, she cannot turn to port or starboard. On the simulator this did not happen and the ship continued turning, thereby continuing to operate the simulator more than a real ship.

It should be indicated that the Captains have experience in operating the R-Class ships only, and both of them indicated that they could notice the difference in ship performance when they exercised the Polar Class mathematical model on the simulator. This emphasizes the benefits of using the simulator in training especially when the trainee has no real life experience onboard a specific type of ship.

## D) VISUALS

1. Both Captains emphasized the fact that the nocturnal view was barely sufficient for the simulation process.

2. The Captains also indicated that the daylight graphics are essential to help the ice navigator in:

    a) Determining the distance between own ship and target ship in close quarter situations. In real life the distance estimation depends greatly on the ice navigator's visual judgement.

    b) Identifying the ice thickness, type and condition. This identification helps the ice navigator to choose the appropriate manoeuvre.

3. While having only nocturnal view, the Captains mentioned that the simulator of own ship engine-noise and the sound of interaction between own ship and ice will have a significant effect on the realism of the simulator and modify the trainee's perception.

4. Capt. Toomey indicated that the configuration of lights onboard the target ship was sufficient but the number of lights on the deck and stern was not. The height of the light, from a distance less than 0.5 nautical miles, was too high and not realistic. Also because of the limitations of the graphics there was no silhouette for the target ship, which caused some difficulty in judging the distance between the two ships.

## E) SCENARIOS

1. The scenarios were sufficient for testing the ships performance but were too simple to be used in training.

2. The scenarios need to be more sophisticated to force the trainee to perform difficult manoeuvres.

3. Both Captains agreed that the most realistic simulation of the ship performance and manoeuvrability was in thick ice (Exercise 2B and 3B) and also with a finer grid size.

## F) GENERAL COMMENTS

The general comments written below are obtained from the evaluation form, the cassette tapes, and verbal discussions with the Captains.

1. The field of view of the 'out of window' visuals was very limited. The present viewing of angle covers 120 degrees (from the stem to 60 degrees on each side). The Captains suggested the field of view be increased to 270 degrees (from the stem to 135° on each side). This will cover the bow, beam, and four points abaft the beam on each side. Capt. Hann indicated that if the simulation process in the future will include the escorting procedures, then the stern view will also be important.

   In such case, the simulator should be equipped by a field of view (projectors and screens) covering 360 degrees around the bridge.

2. Upgrading the system to accommodate daylight graphics is essential.

3. The Captains indicated that it is important to have some flexibility in changing the bridge instruments to represent the real ship bridge. For example, on the bridge of a Polar Class ship, a third throttle to control the centre propeller is essential.

4. In some cases, the ship performance, communication between own ship and target ship, and the bridge procedures were very realistic.

# 6. CONCLUSIONS AND RECOMMENDATIONS

## 6.1 General Conclusions

A number of general conclusions have been drawn as a result of the present study. These are summarized below:

- The capabilities of CABINS as a full bridge navigation simulator have been found to be adequate for operational evaluation.
- The hydrodynamic models residing within CABINS are flexible enough to accommodate additional modules that will handle ice forces on the hull due to level icebreaking.
- The radar imagery can be modified within the existing set up to provide the most important information required for ice navigation, namely the broken track.
- Visual clues on the screen can provide sufficient details of a beset ship at distance.
- Existing hardware can handle the addition of the above features without unduly slowing down the system and the simulation can be repeated without long initialization procedures.
- Hard copy output and recordings of captain's comments are adequate information for assessing the success of the simulation.

## 6.2 Specific Conclusions

The following specific conclusions were drawn as a result of the operational evaluation:

- The hydrodynamic models developed for the R-Class as well as the Polar Class vessels are judged to be about 70% realistic. This indicates that the modelling approach is essentially sound and the assumptions used are justifiable.
- The degree of realism that can be associated with the bridge set-up and display is estimated as 76%.
- One of the captain's judged the mathematical models for steady turning in ice to be adequately realistic while the other found it wanting in realism. It is concluded that improvements to the ice force algorithm will require more full scale data.
- There was unanimous agreement in the inadequacy of nocturnal vision for simulations in ice. This was expected and future efforts in development will aim for daylight vision.

- Scenarios selected were judged to be effective in aiding the operational evaluation. Hence future work can use the present approach as a reliable starting point for planning of validation exercises.

## 6.3 Recommendations for Further Enhancement of CABINS

### 6.3.1 The Visuals

1. The daylight graphics enhancement, with a control on the different visibility conditions, are essential to obtain the desired goals. This will require mainly modification to the software and the purchase of the necessary supporting hardware.

2. Upgrading the simulator to have 270 degrees or 360 degrees field of view. This will require the purchase of the appropriate hardware.

### 6.3.2 Models

1. Modifications should be made to improve the capabilities of the mathematical models in broken ice for ahead and astern movements.

2. The interaction between the ship mathematical model and ice while going across the broken channel should be included as a part of the ice force algorithm.

3. Some research should be done to determine the most appropriate grid size. These will constitute software modifications allowing grid size variations with ice thickness and ship particulars.

### 6.3.3 Radar

The simulated radar image should be modified to provide a higher resolution and increased update rate. This will require modification to the software and the purchase of some hardware.

### 6.3.4 The Audio System

1. The sound of own ship engine noise and the sound of interaction between own ship and different types of ice will add to the realism of the simulator. This will need modification to the software and the purchase of some hardware.

2. A motion platform will add to the simulation environment. It will be used mainly to simulate own ship engine vibrations and the interaction with ice. This will need a major change in the physical bridge configuration and major change in the software and hence are not envisaged for the immediate future.

# 7. REFERENCES

[1] Tue-fee, K.K., and Keinonen, A.I., Menon, B.C., and Bayly, I.M. "Model for Predicting Steady Turning Performance of Conventional Icebreakers in Level Unbroken Ice". The Royal Institution of Naval Architects International Conference on Ship Manoeuvrability - Predictions and Achievement, 1987.

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[3] McCallum, I.R., "Ship Steering Mathematical Model for all" Manoeuvring Regimes", Proc. IIC Symposium on Ship Steering Automatic Control, Genoa, June 25-27, 1980, pp. 119-139.

[4] Nomoto, K., "Problems and Requirements of Directional Stability and Control of Surface Ship, Journal of Mechanical Engineering Science, Vol. 14, No. 7, 1972, pp. 1-5.

[5] "Development of a Semi-empirical Model for Predicting Resistance and Determining Thrust Requirements for Ships in Level Ice", by Arctec Canada Limited. Prepared for the Transportation Development Centre in 1983, TP No. 4375E.

[6] Edwards, R.Y. et al, "Results of Trials in Ice and Open Water of CCGS PIERRE RADISSON", Arctec Canada Report for CCG, 1979.

[7] Menon, B., Edgecombe, M., Tue-fee, K.K. and Glen, I.F., "Manoeuvring Tests in Ice Aboard USCGC POLAR STAR in Antarctica 1985", Report to Transportation Development Centre, TP8297E, 1986.

[8] McCallum, I.R., Matthews, R., "A Modular Manoeuvring Mathematical Model for Warship Simulation". Proc. 1st International Symposium on Marine Simulation, Munich, June 3-5, 1985, pp. 175-190. Pub. Springer-Verlag, ISBN 3-540-15620-8.

# APPENDIX A

# RESULTS OF EXERCISES AND OUTPUT OF CAPTAIN'S EVALUATION TASK

## EXERCISE MATRIX

| LEGEND | VESSEL | ICE THICKNESS | ICE COVERAGE | EXERCISE NUMBER |
|---|---|---|---|---|
| R50H | R-Class | 50 cm | half ice/half water | 1 |
| R50C | R-Class | 50 cm | constant ice thickness | 2A |
| R100C | R-Class | 100 cm | constant ice thickness | 2B |
| R50V | R-Class | 50 cm | ±20% variable ice thickness | 3A |
| R100V | R-Class | 100 cm | ±20% variable ice thickness | 3B |
| R50XF | R-Class | 50 cm | variable ice thickness with fine grid | 4 |
| P80H | Polar Class | 80 cm | half ice/half water | 1 |
| P80C | Polar Class | 80 cm | constant ice thickness | 2A |
| P160C | Polar Class | 160 cm | constant ice thickness | 2B |
| P80V | Polar Class | 80 cm | ±20% variable ice thickness | 3A |
| P160V | Polar Class | 160 cm | ±20% variable ice thickness | 3B |
| P80XF | Polar Class | 80 cm | variable ice thickness with fine grid | 4 |

Captn Ham R class No. 1

## VALIDATION FORM

### EVALUATING THE SHIP'S MODEL

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 8 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

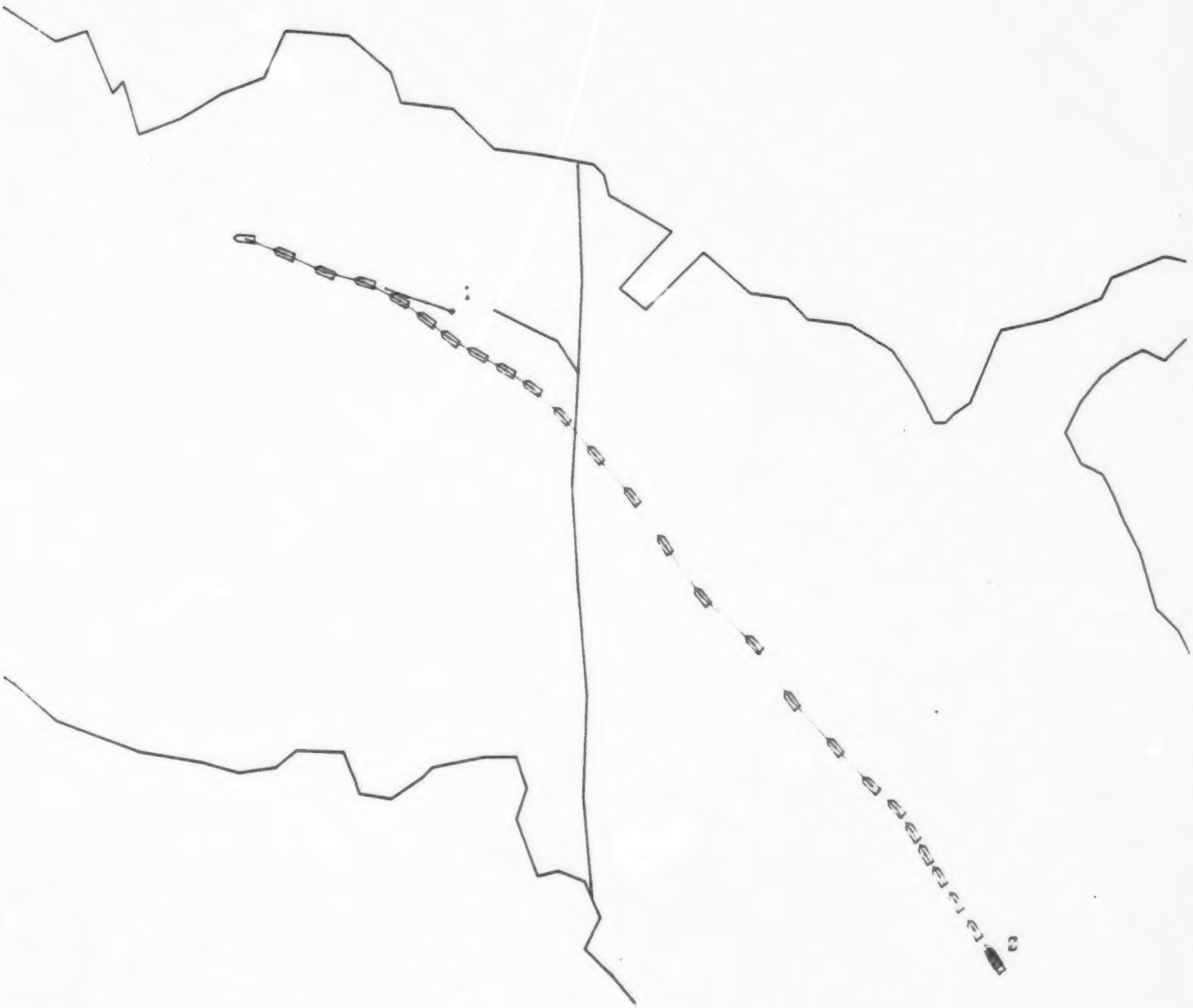
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 7 [✓ 8] 9 10

| | |
|---|---|
| Run | RS0H |
| Date | 22-02-88 |
| Time | 09:45 |
| Pilot: | E. HANN |



R - class No - 2A

# VALIDATION FORM

## EVALUATING THE SHIP'S MODEL

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 8 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

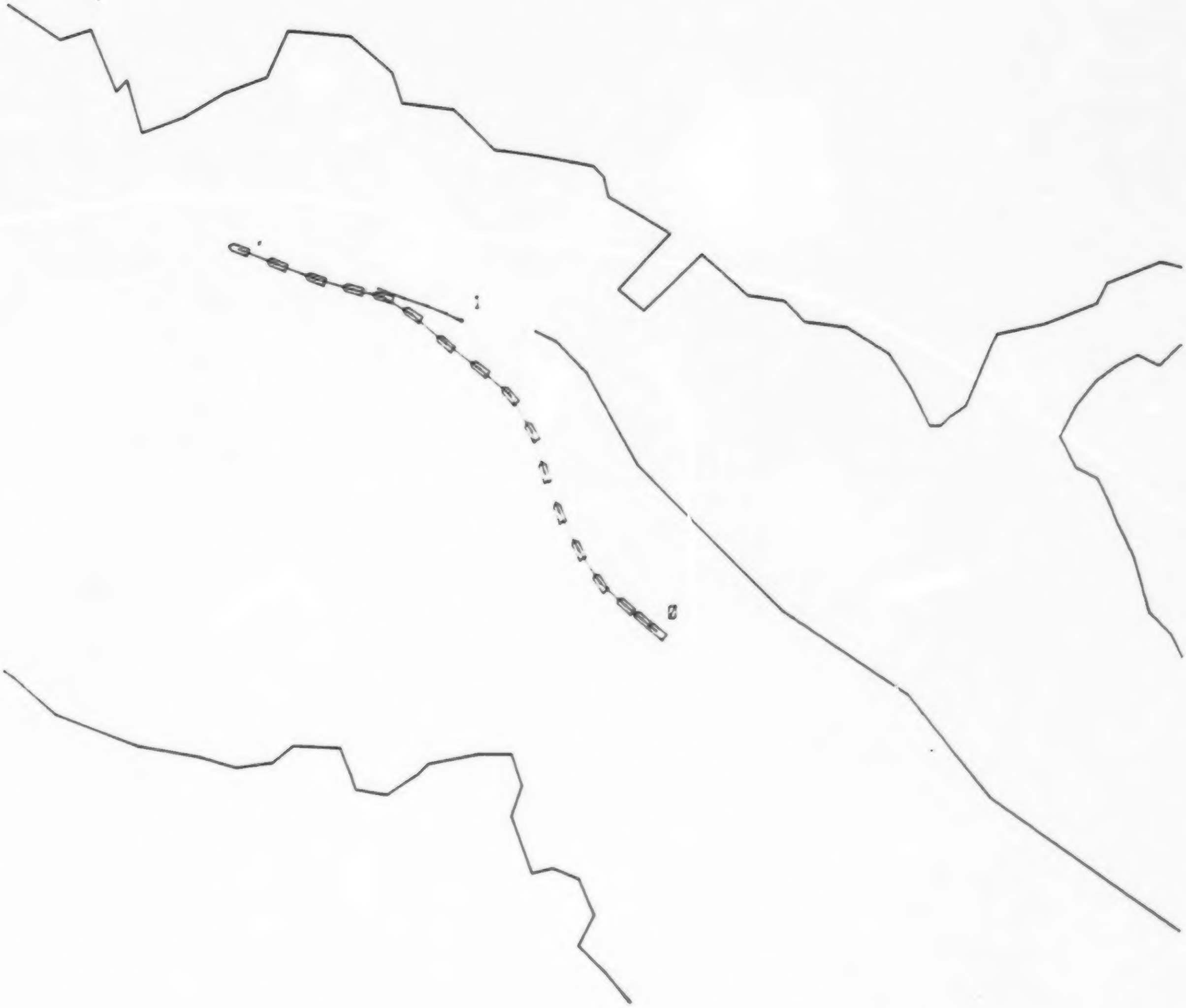
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 7 [✓ 8] 9 10

| | |
|---|---|
| Run | R50C |
| Date | 22-02-88 |
| Time | 10:25 |
| Pilot: | E. HANN |



R-class No. 2B

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10
Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10
Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

3. The rate of turn (as a result of the rudder's angle)

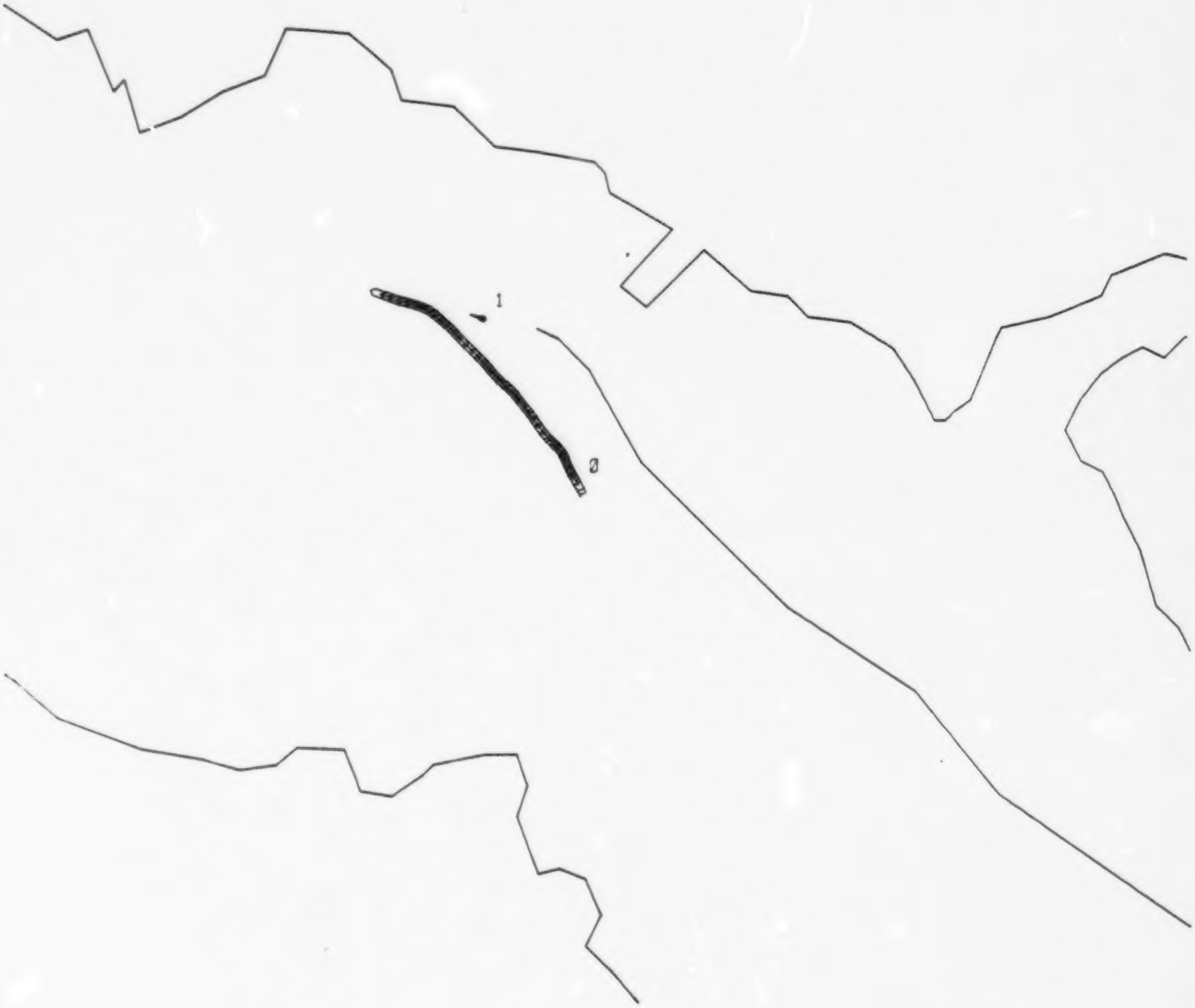
To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10
To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10
To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 7 [✓ 8] 9 10

Run R100C
Date 22-02-88
Time 10:45
Pilot: E. HANN



R-class No. 2A

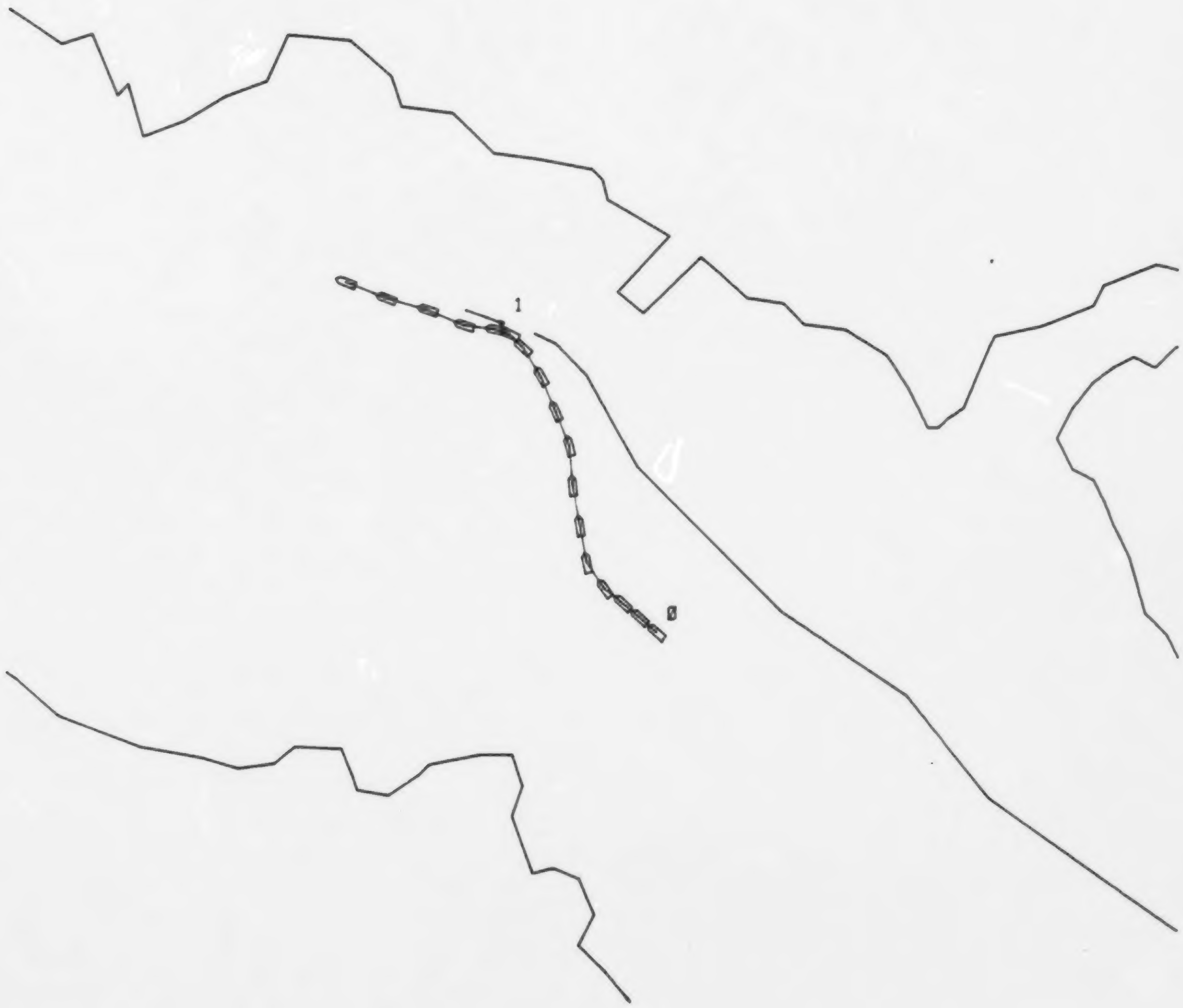
VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. The rate of acceleration | | | | | | | | | | |
| Ahead | 1 | 2 | 3 | 4 | 5 | 6 | 7 | [✓ 8] | 9 | 10 |
| Astern | 1 | 2 | 3 | 4 | 5 | 6 | 7 | [✓ 8] | 9 | 10 |
| 2. The rate of deceleration | | | | | | | | | | |
| Ahead | 1 | 2 | 3 | 4 | 5 | 6 | 7 | [✓ 8] | 9 | 10 |
| Astern | 1 | 2 | 3 | 4 | 5 | 6 | 7 | [✓ 8] | 9 | 10 |
| 3. The rate of turn (as a result of the rudder's angle) | | | | | | | | | | |
| To Starboard | 1 | 2 | 3 | 4 | 5 | 6 | 7 | [✓ 8] | 9 | 10 |
| To Port | 1 | 2 | 3 | 4 | 5 | 6 | 7 | [✓ 8] | 9 | 10 |
| 4. The rate of turn (as a result of using the propellers one ahead and one astern. | | | | | | | | | | |
| To Starboard | 1 | 2 | 3 | 4 | 5 | 6 | 7 | [✓ 8] | 9 | 10 |
| To Port | 1 | 2 | 3 | 4 | 5 | 6 | 7 | [✓ 8] | 9 | 10 |
| 5. The rate of turn (as a result of using the propellers and the rudder). | 1 | 2 | 3 | 4 | 5 | 6 | 7 | [✓ 8] | 9 | 10 |

Run RS0V
Date 22-02-88
Time 11:25
Pilot: E. HANN



R-class No.3E

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

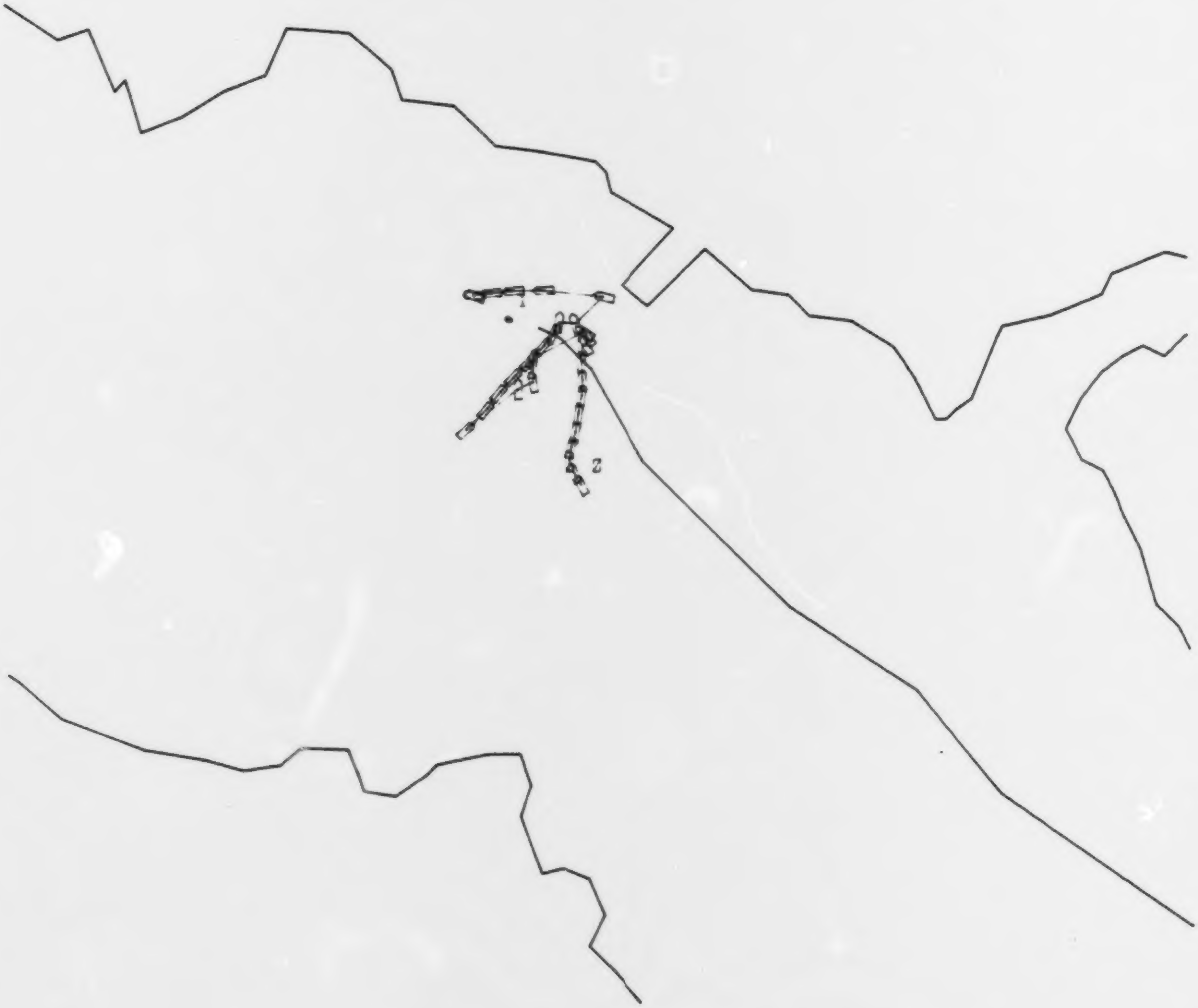
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard [✓ 1] 2 3 4 5 6 7 8 9 10

To Port [✓ 1] 2 3 4 5 6 7 8 9 10

5. The rate of turn (as a result of using the propellers and the rudder). [✓ 1] 2 3 4 5 6 7 8 9 10

Run R100V
Date 23-02-88
Time 09:30
Pilot: E. HANN



R-class No. 4

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

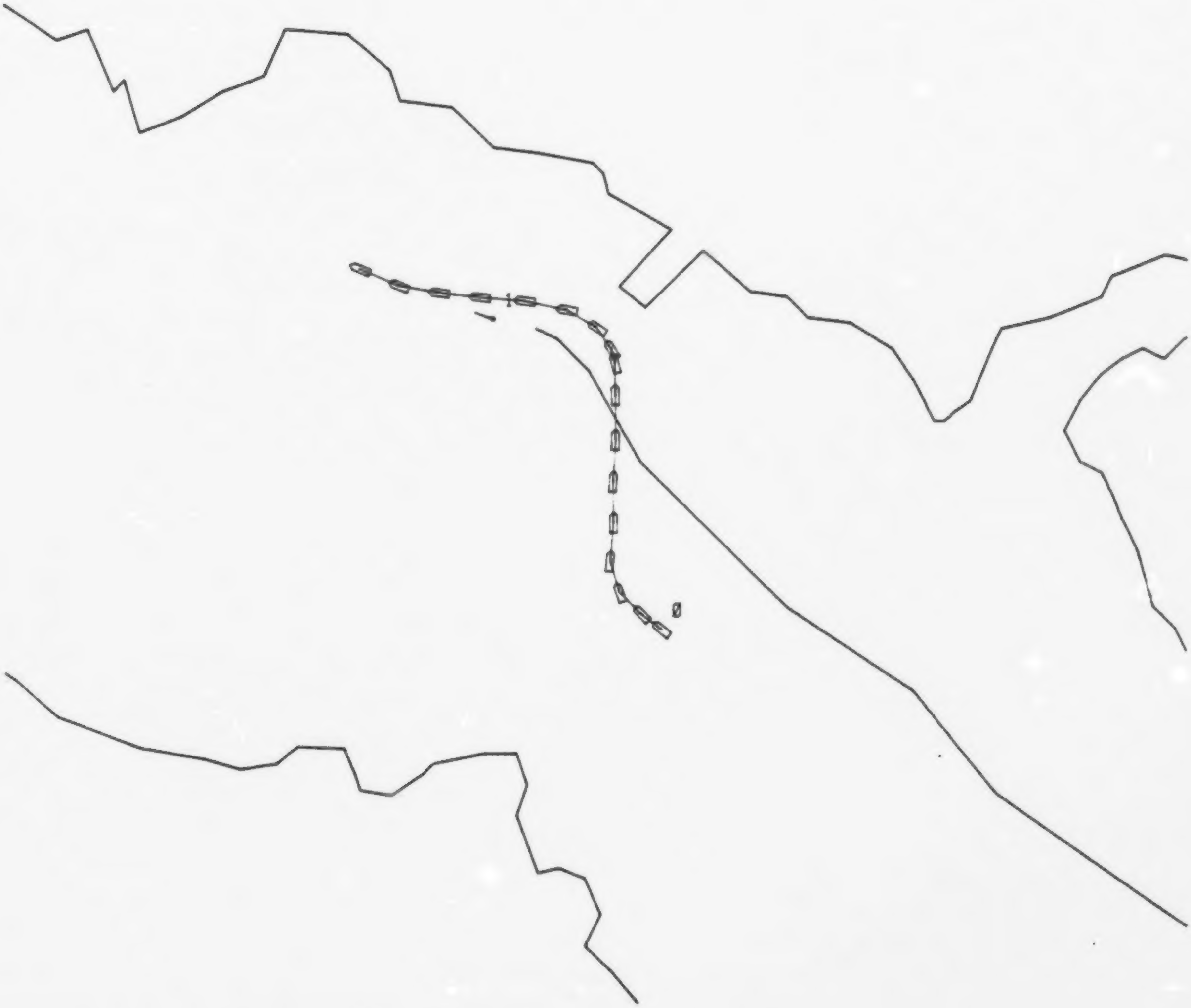
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 [✓ 2] 3 4 5 6 7 8 9 10

To Port 1 [✓ 2] 3 4 5 6 7 8 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 [✓ 2] 3 4 5 6 7 8 9 10

| | |
|---|---|
| Run | R50XF |
| Date | 23-02-88 |
| Time | 10:40 |
| Pilot: | E. HANN |



Polar Class No.

## VALIDATION FORM

### EVALUATING THE SHIP'S MODEL

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 [✓ 7] 8 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 [✓ 7] 8 9 10

Astern 1 2 3 4 5 6 [✓ 7] 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

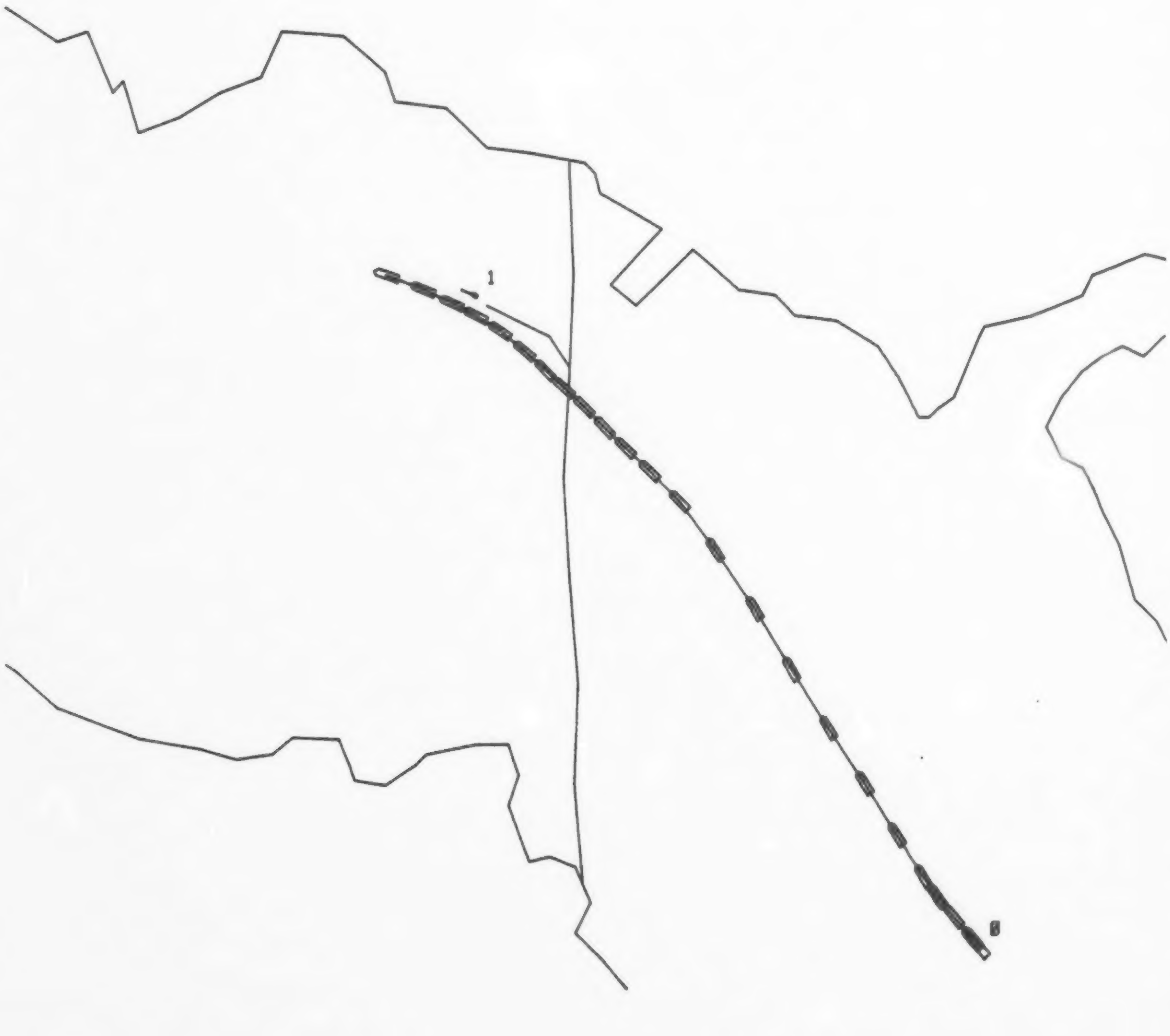
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 7 [✓ 8] 9 10

| | |
|---|---|
| Run | P80H |
| Date | 22-02-88 |
| Time | 14:20 |
| Pilot: | E. HANN |



Polar class No 2

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

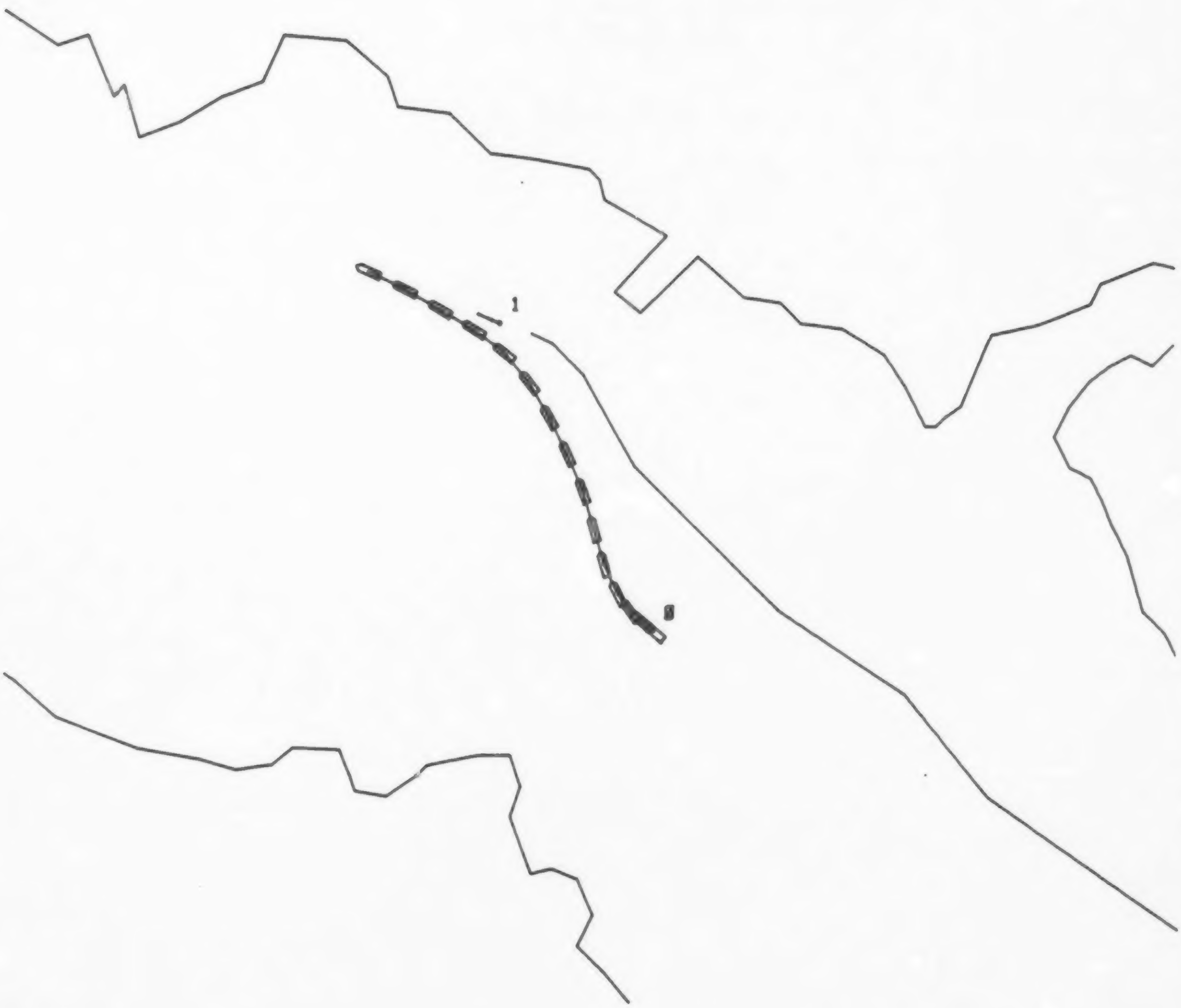
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 7 [✓ 8] 9 10

Run P80C
Date 22-02-88
Time 14:50
Pilot: E. HANN



Polar class No 21

## VALIDATION FORM

### EVALUATING THE SHIP'S MODEL

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

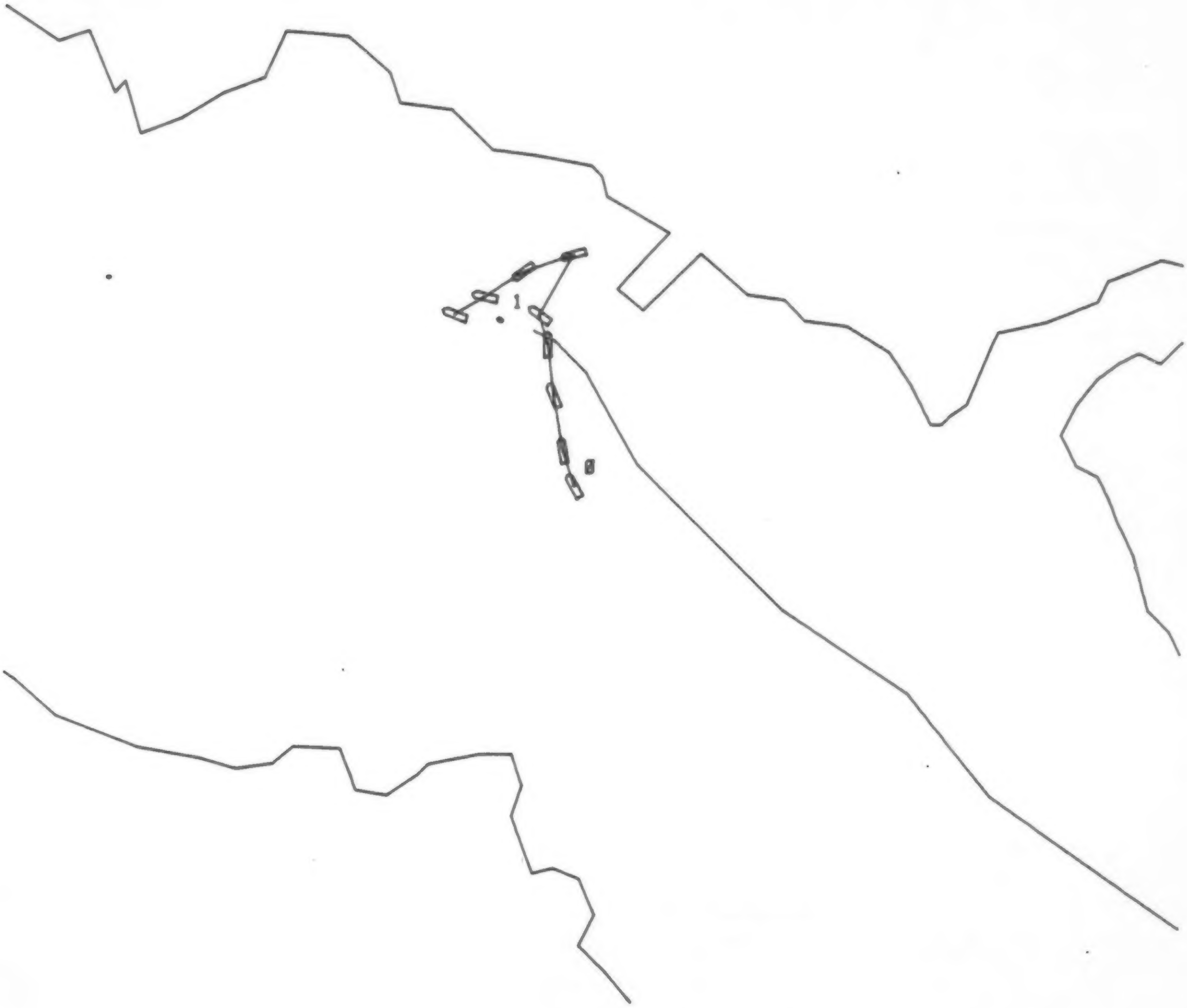
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 [✓ 5] 6 7 8 9 10

To Port 1 2 3 4 [✓ 5] 6 7 8 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 [✓ 5] 6 7 8 9 10

| | |
|---|---|
| Run | P160C |
| Date | 22-02-88 |
| Time | 15:10 |
| Pilot: | E. HANN |



Polar class No. 3A

## VALIDATION FORM

### EVALUATING THE SHIP'S MODEL

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

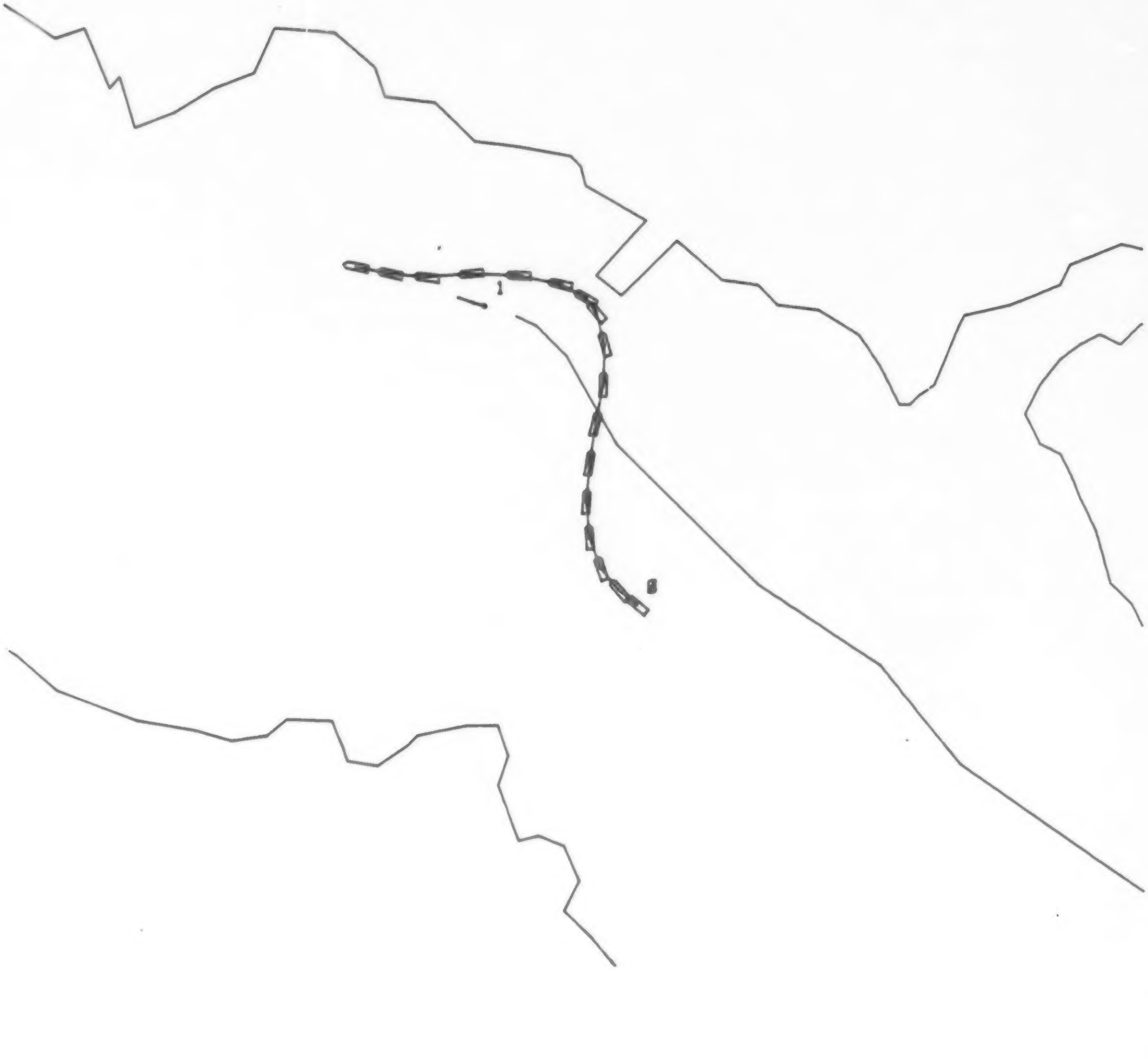
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard [✓ 1] 2 3 4 5 6 7 8 9 10

To Port [✓ 1] 2 3 4 5 6 7 8 9 10

5. The rate of turn (as a result of using the propellers and the rudder). [✓ 1] 2 3 4 5 6 7 8 9 10

| | |
|---|---|
| Run | P80V |
| Date | 22-02-88 |
| Time | 15:45 |
| Pilot: | E. HANN |



Polar class No. 3

VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

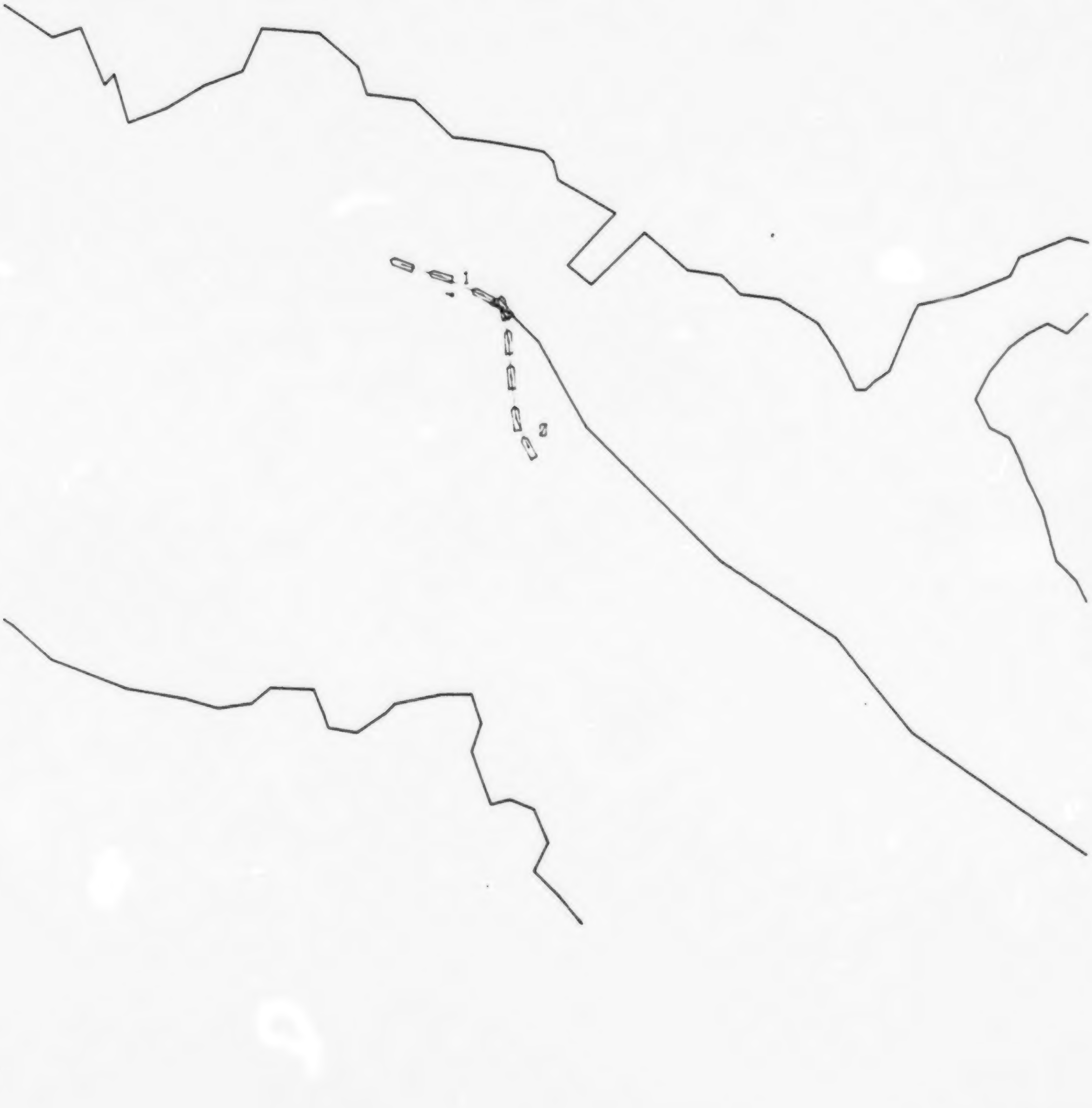
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 7 [✓ 8] 9 10

| | |
|---|---|
| Run | P160V |
| Date | 23-02-88 |
| Time | 11:05 |
| Pilot: | E. HANN |



Polar class No- 4

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

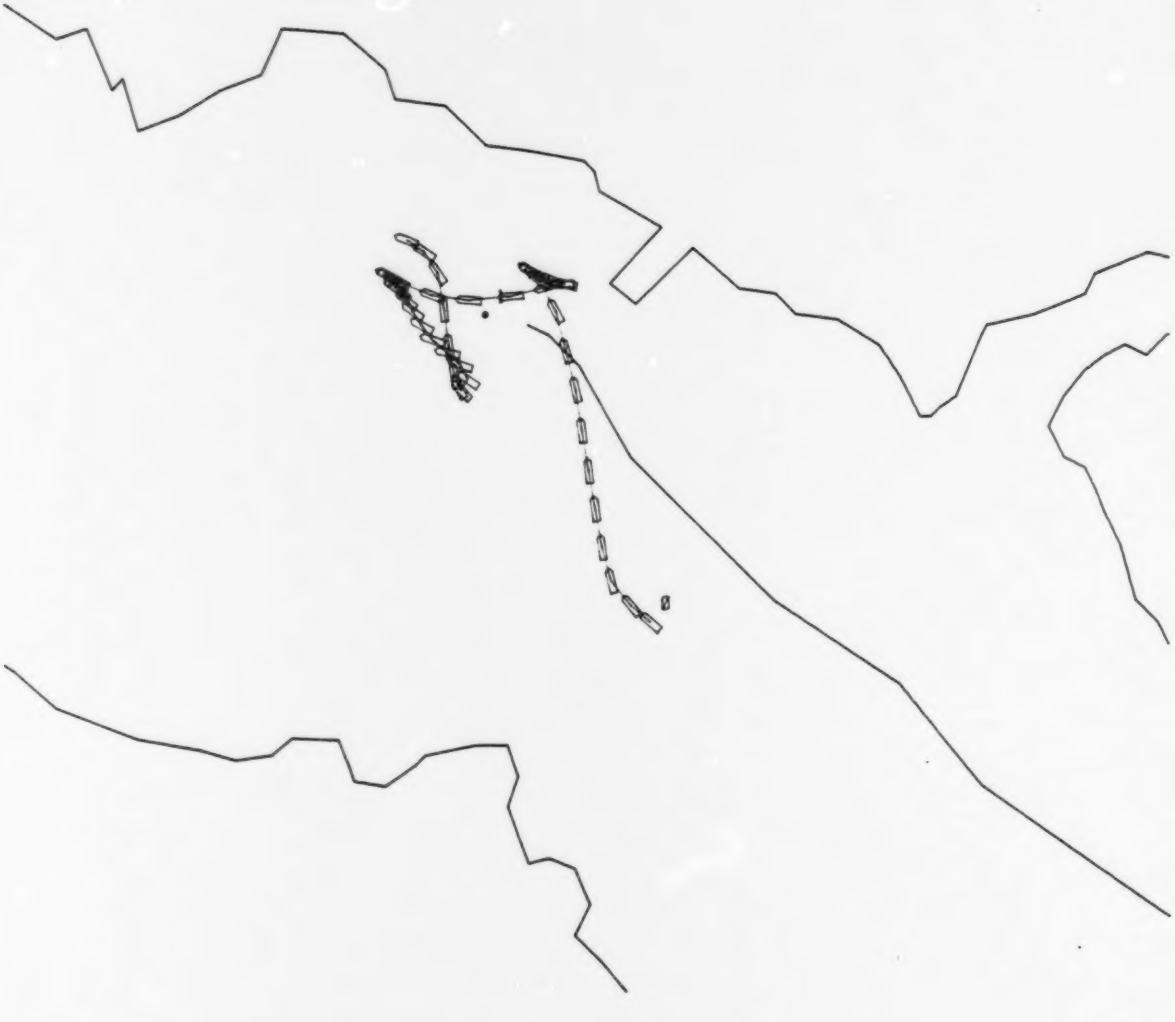
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 [✓ 5] 6 7 8 9 10

To Port 1 2 3 4 [✓ 5] 6 7 8 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 [✓ 5] 6 7 8 9 10

Run P80XF
Date 23-02-88
Time 11:45
Pilot: E. HANN



Capt. Toomey

R-Class - Exercise No. 1

## VALIDATION FORM

### EVALUATING THE SHIP'S MODEL

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 [✓ 4] 5 6 7 8 9 10

Astern 1 2 3 4 5 6 7 8 9 10

2. The rate of deceleration

Ahead 1 2 3 4 [✓ 5] 6 7 8 9 10

Astern 1 2 3 4 5 6 7 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 [✓ 7] 8 9 10

To Port 1 2 3 4 5 6 [✓ 7] 8 9 10

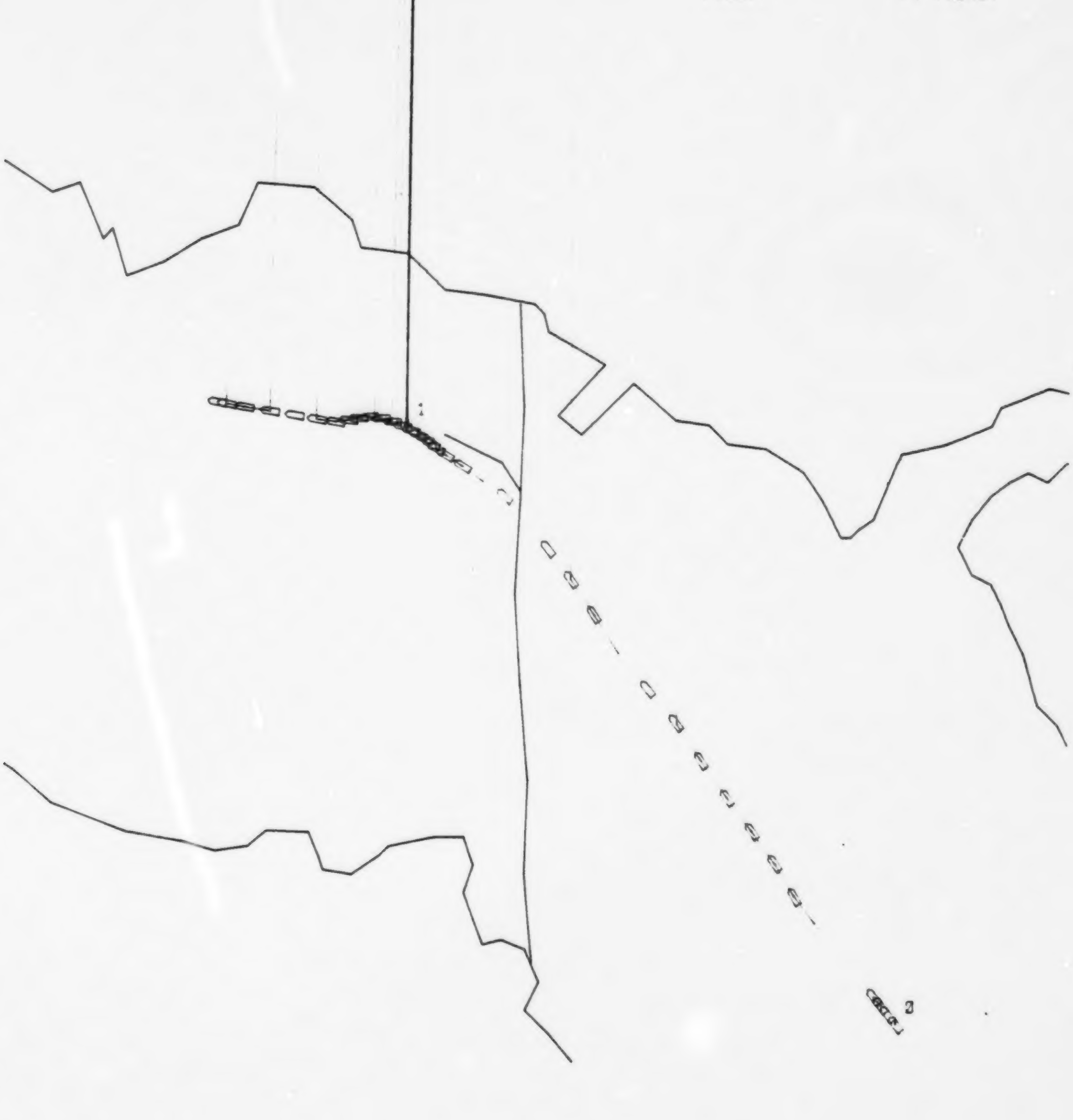
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 8 9 10

To Port 1 2 3 [✓ 4] 5 6 7 8 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 [✓ 6] 7 8 9 10

| | |
|---|---|
| Run | R50H |
| Date | 03-03-88 |
| Time | 10:45 |
| Pilot: | P. TOOMEY |



R-class Exercise No. 2A

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 [✓ 4] 5 6 7 8 9 10

Astern 1 2 3 4 5 6 [✓ 7] 8 9 10

2. The rate of deceleration

Ahead 1 2 3 [✓ 4] 5 6 7 8 9 10

Astern 1 2 3 4 [✓ 5] 6 7 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 [✓ 7] 8 9 10

To Port 1 2 3 4 5 6 [✓ 7] 8 9 10

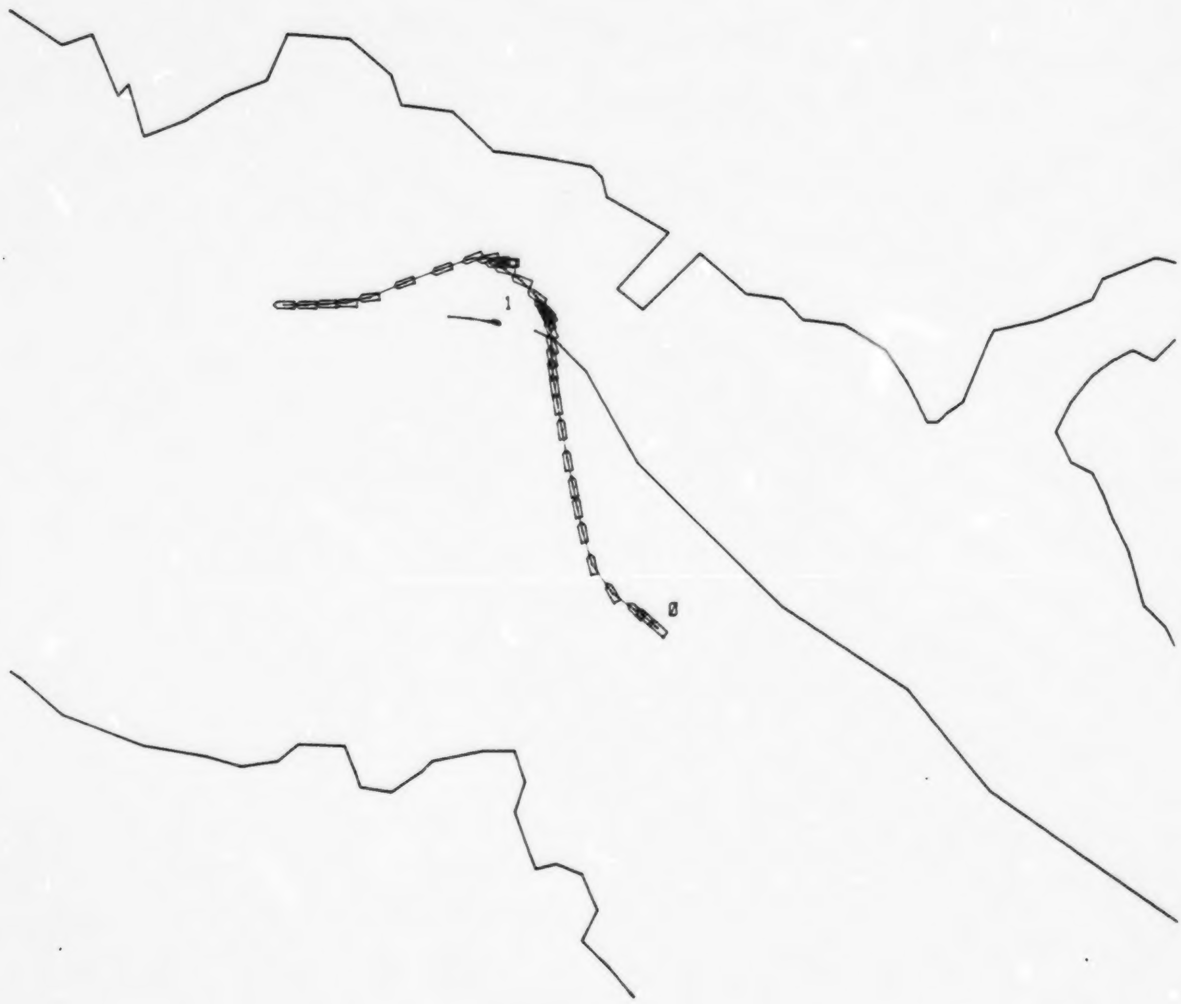
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 [✓ 6] 7 8 9 10

To Port 1 2 3 4 [✓ 5] 6 7 8 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 7 [✓ 8] 9 10

| | |
|---|---|
| Run | R50C |
| Date | 03-03-88 |
| Time | 11:15 |
| Pilot: | P. TOOMEY |



R-Class Exercise No.28

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 [✓ 5] 6 7 8 9 10

Astern 1 2 3 4 5 6 7 8 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 [✓ 6] 7 8 9 10

Astern 1 2 3 4 5 6 7 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 [✓ 7] 8 9 10

To Port 1 2 3 4 5 6 [✓ 7] 8 9 10

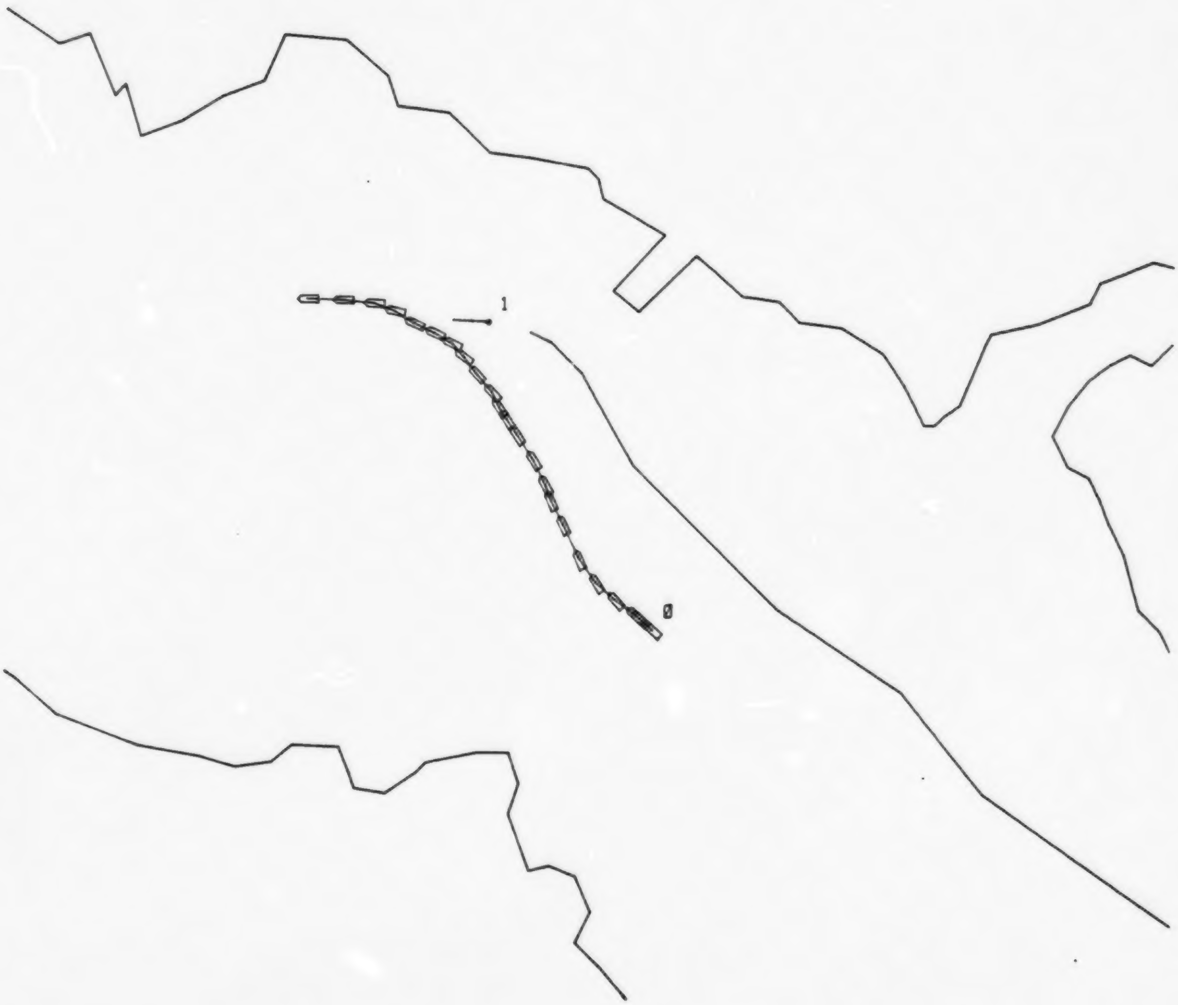
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 8 9 10

To Port 1 2 3 4 5 [✓ 6] 7 8 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 [✓ 7] 8 9 10

Run R50V
Date 03-03-88
Time 11:50
Pilot: P. TOOMEY



R-class Exercise N°3 A

# VALIDATION FORM

## EVALUATING THE SHIP'S MODEL

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 8 [✓ 9] 10

To Port 1 2 3 4 5 6 7 8 [✓ 9] 10

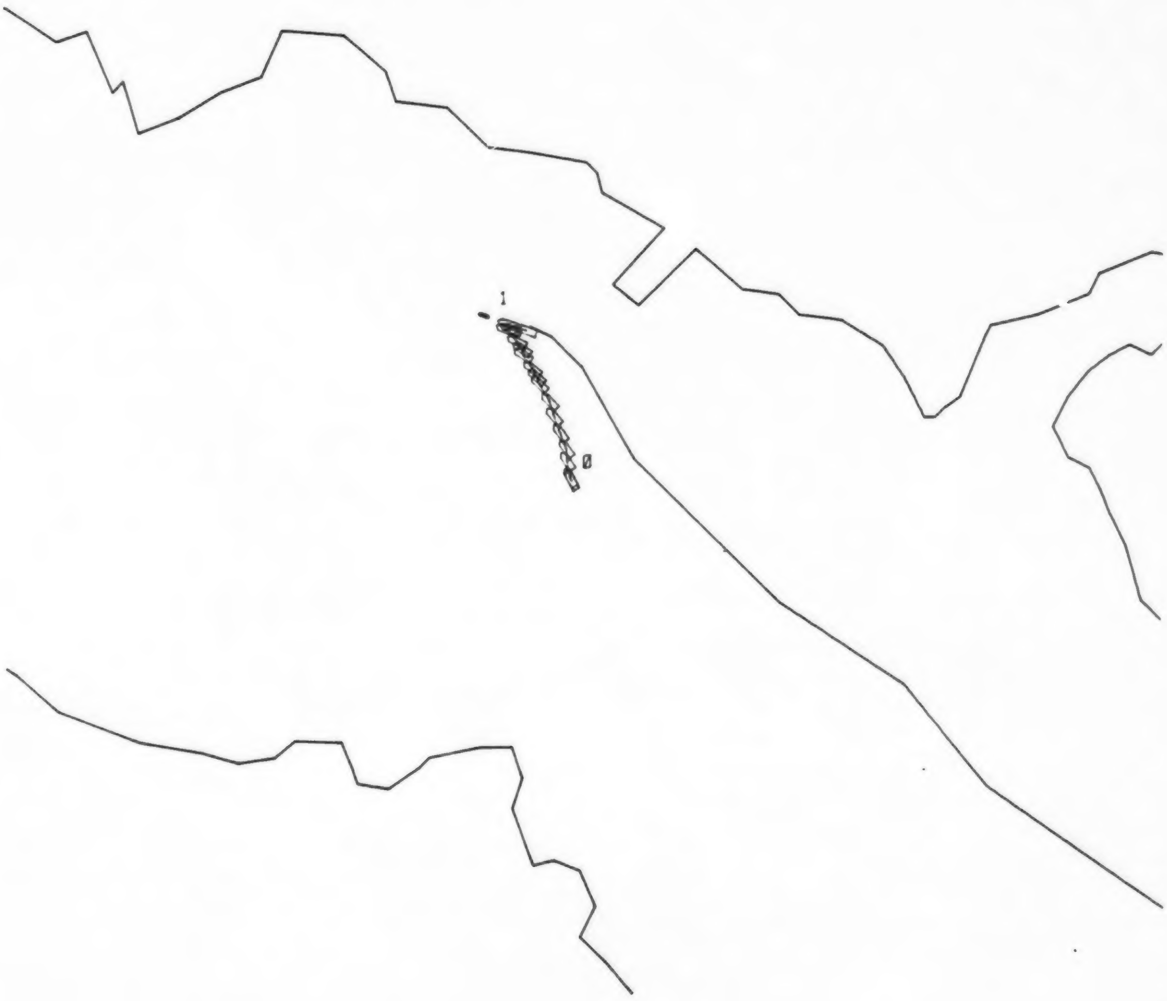
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 8 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 7 [✓ 8] 9 10

| | |
|---|---|
| Run | R100C |
| Date | 03-03-88 |
| Time | 12:15 |
| Pilot: | P. TOOMEY |



R Class Exercise #3E

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 [✓ 7] 8 9 10

Astern 1 2 3 4 5 6 7 [✓ 8] 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 [✓ 7] 8 9 10

Astern 1 2 3 4 5 [✓ 6] 7 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 [✓ 7] 8 9 10

To Port 1 2 3 4 5 6 [✓ 7] 8 9 10

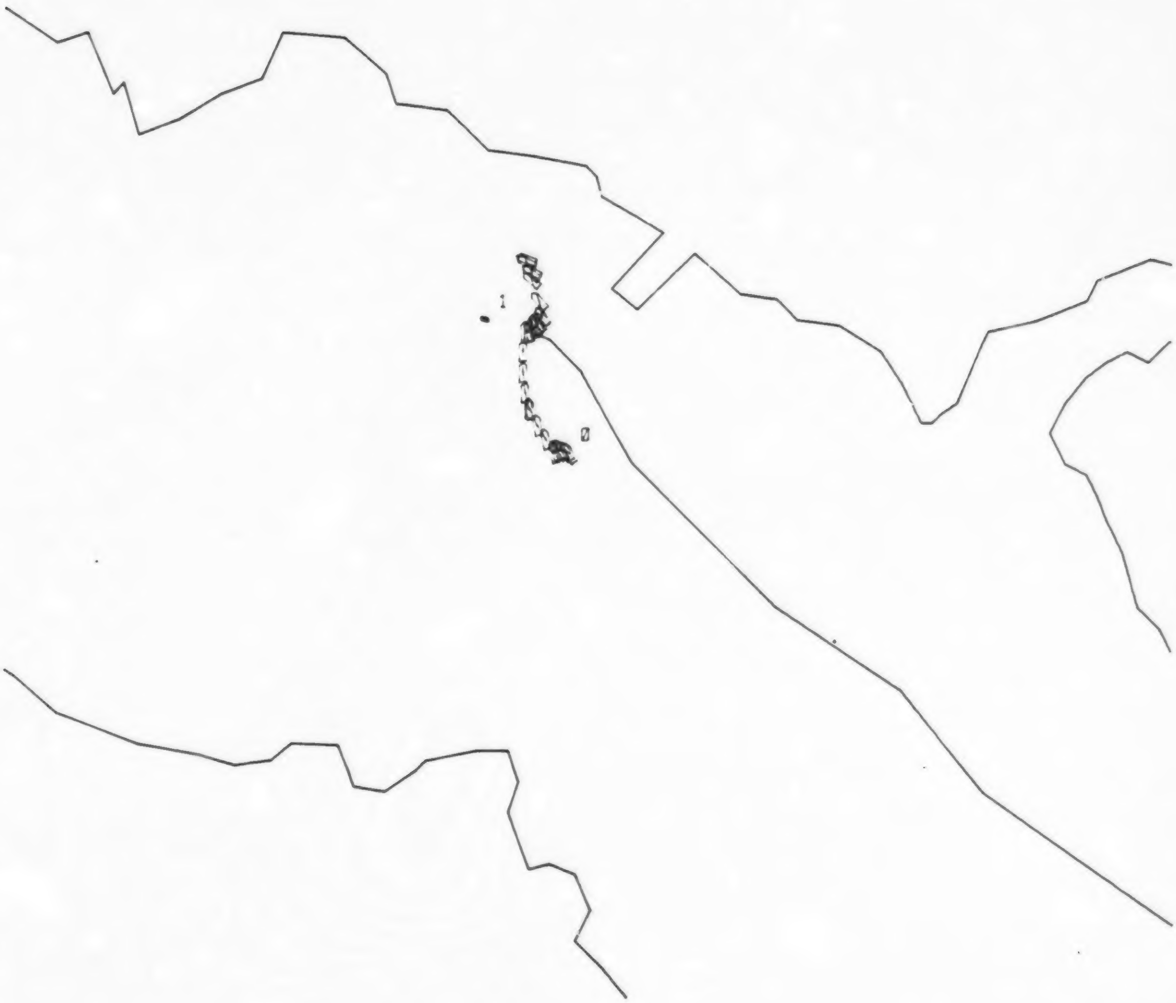
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 [✓ 5] 6 7 8 9 10

To Port 1 2 3 4 [✓ 5] 6 7 8 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 [✓ 4] 5 6 7 8 9 10

| | |
|---|---|
| Run | R100V |
| Date | 03-03-88 |
| Time | 14:10 |
| Pilot: | P. TOOMEY |



R-class Exercise No

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 [✓ 6] 7 8 9 10

Astern 1 2 3 4 [✓ 5] 6 7 8 9 10

2. The rate of deceleration

Ahead 1 2 3 4 [✓ 5] 6 7 8 9 10

Astern 1 2 3 4 [✓ 5] 6 7 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 [✓ 7] 8 9 10

To Port 1 2 3 4 5 6 [✓ 7] 8 9 10

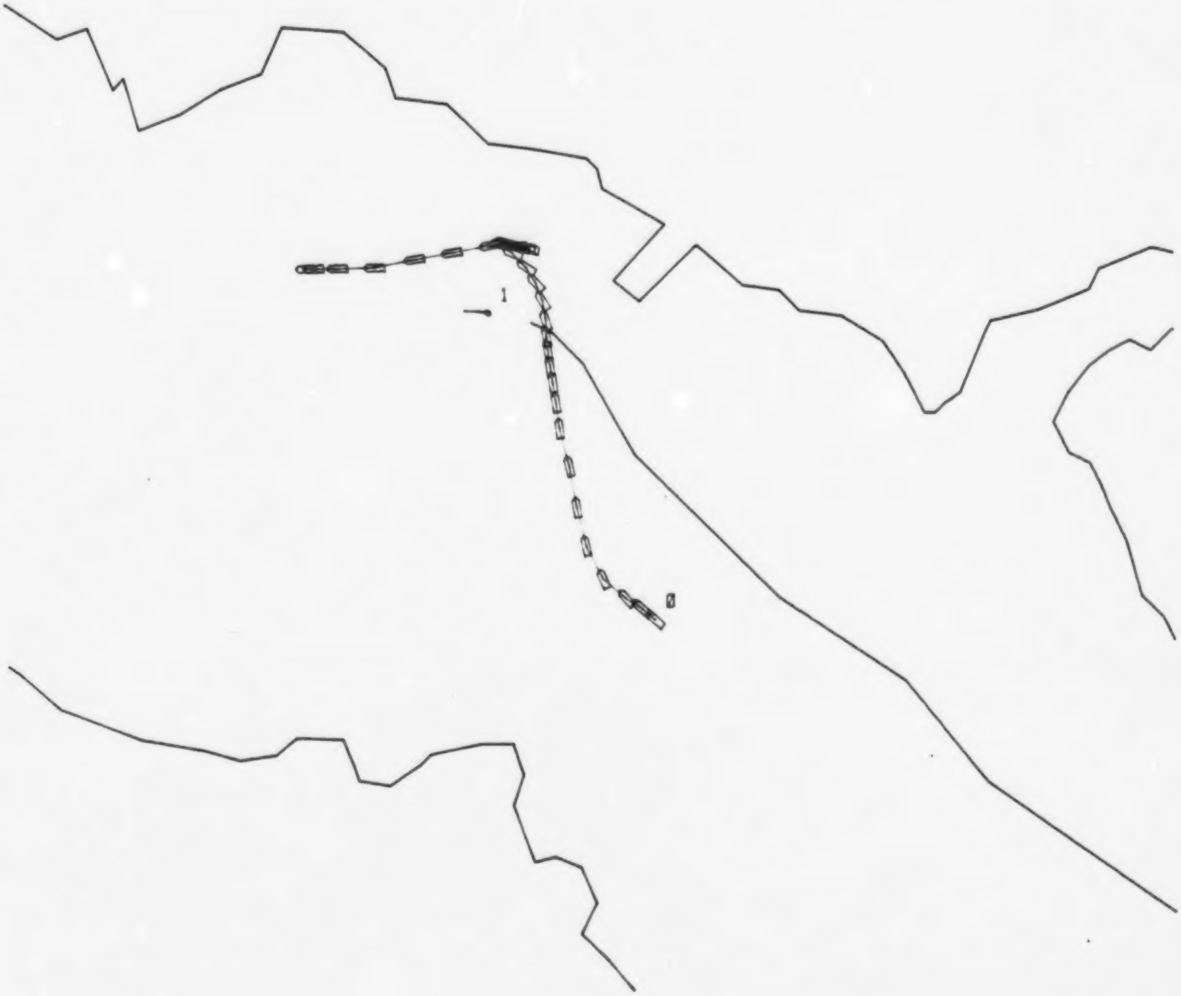
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 8 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 [✓ 7] 8 9 10

Run R50XF
Date 03-03-88
Time 15:20
Pilot: P. TOOMEY



Polo class Excercise No

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 [✓ 6] 7 8 9 10

Astern 1 2 3 4 [✓ 5] 6 7 8 9 10

2. The rate of deceleration

Ahead 1 2 3 4 [✓ 5] 6 7 8 9 10

Astern 1 2 3 4 5 6 [✓ 7] 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 [✓ 7] 8 9 10

To Port 1 2 3 4 5 6 [✓ 7] 8 9 10

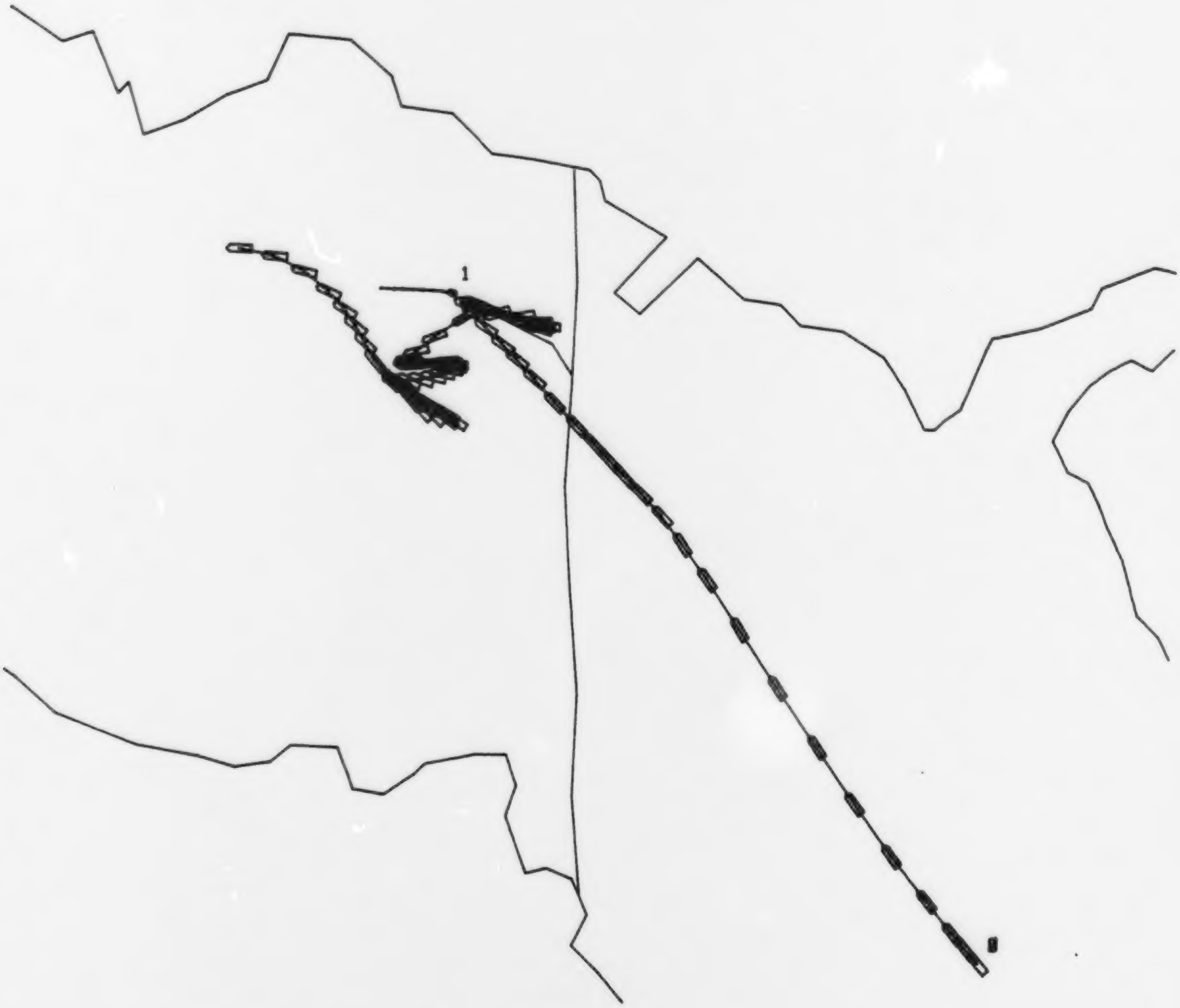
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 [✓ 5] 6 7 8 9 10

To Port 1 2 3 4 [✓ 5] 6 7 8 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 [✓ 4] 5 6 7 8 9 10

Run P80H
Date 03-03-88
Time 15:50
Pilot: P. TOOMEY



Poker Class Exercise No.2

VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

| | |
|---|---|
| Ahead | 1 2 3 [✓ 4] 5 6 7 8 9 10 |
| Astern | 1 2 3 4 5 6 7 8 9 10 |

2. The rate of deceleration

| | |
|---|---|
| Ahead | 1 2 3 [✓ 4] 5 6 7 8 9 10 |
| Astern | 1 2 3 4 5 6 7 8 9 10 |

3. The rate of turn (as a result of the rudder's angle)

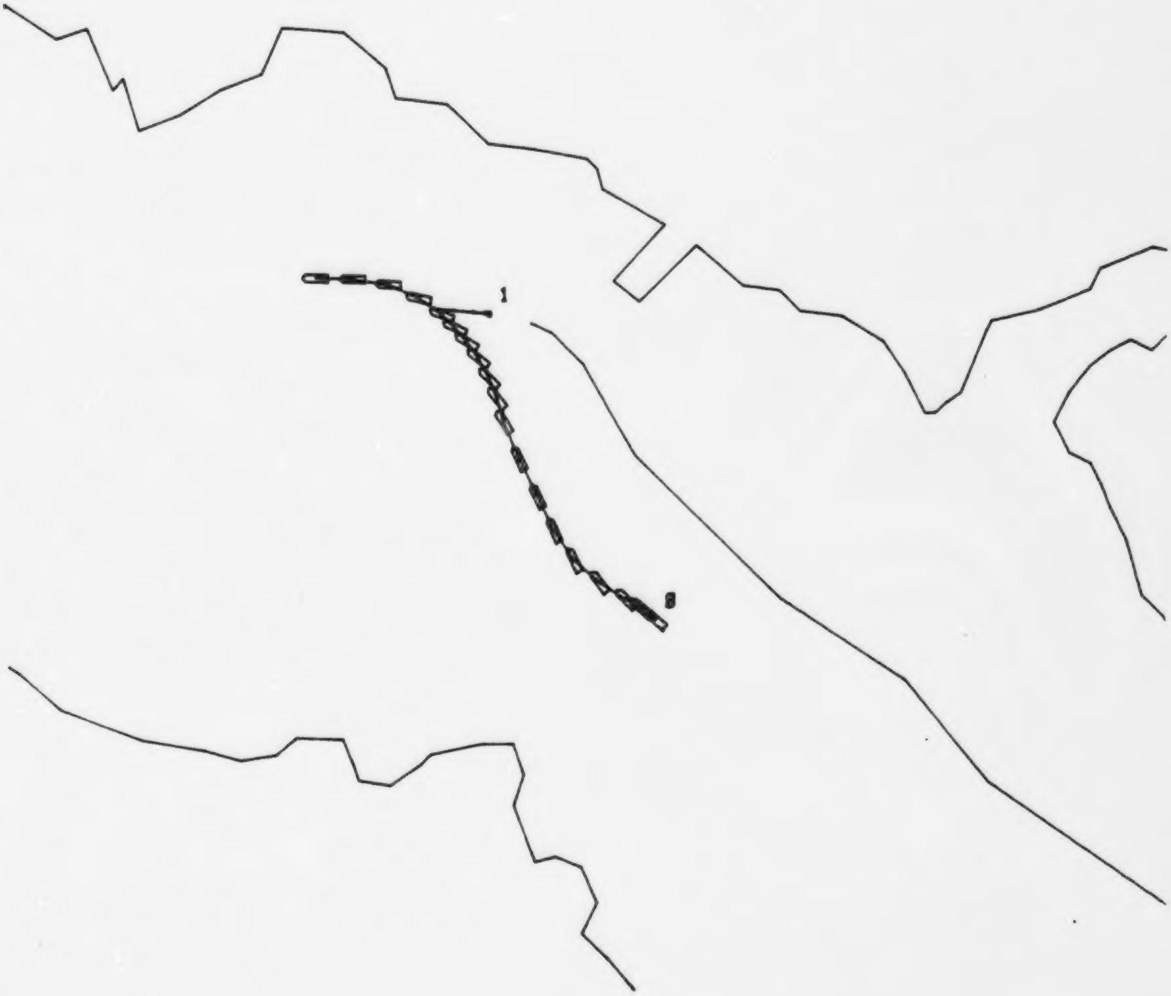
| | |
|---|---|
| To Starboard | 1 2 3 4 5 6 [✓ 7] 8 9 10 |
| To Port | 1 2 3 4 5 6 [✓ 7] 8 9 10 |

4. The rate of turn (as a result of using the propellers one ahead and one astern.

| | |
|---|---|
| To Starboard | 1 2 3 4 5 6 7 8 9 10 |
| To Port | 1 2 3 4 5 6 7 [✓ 8] 9 10 |

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 7 [✓ 8] 9 10

| | |
|---|---|
| Run | P80C |
| Date | 04-03-88 |
| Time | 09:10 |
| Pilot: | P. TOOMEY |



Polar Class – [illegible]

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 7 [✓ 8] 9 10

Astern 1 2 3 4 5 6 [✓ 7] 8 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 6 [✓ 7] 8 9 10

Astern 1 2 3 4 5 6 [✓ 7] 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 8 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

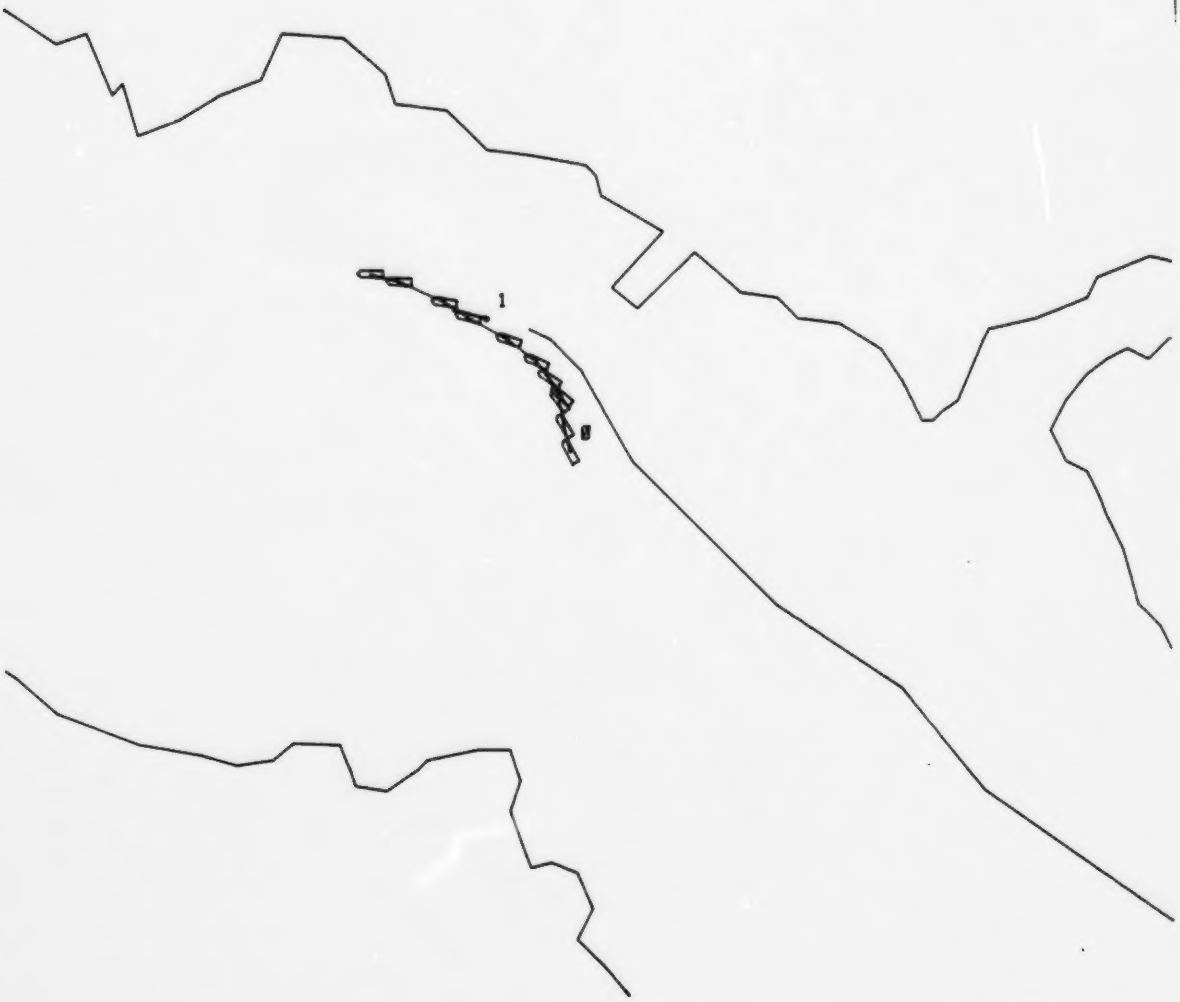
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 8 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 [✓ 7] 8 9 10

| | |
|---|---|
| Run | P160C |
| Date | 04-03-80 |
| Time | 09:40 |
| Pilot: | P. TOOMEY |



Polar class - Exercise No 3

## VALIDATION FORM

**EVALUATING THE SHIP'S MODEL**

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 [✓ 7] 8 9 10

Astern 1 2 3 4 5 6 [✓ 7] 8 9 10

2. The rate of deceleration

Ahead 1 2 3 4 [✓ 5] 6 7 8 9 10

Astern 1 2 3 4 [✓ 5] 6 7 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

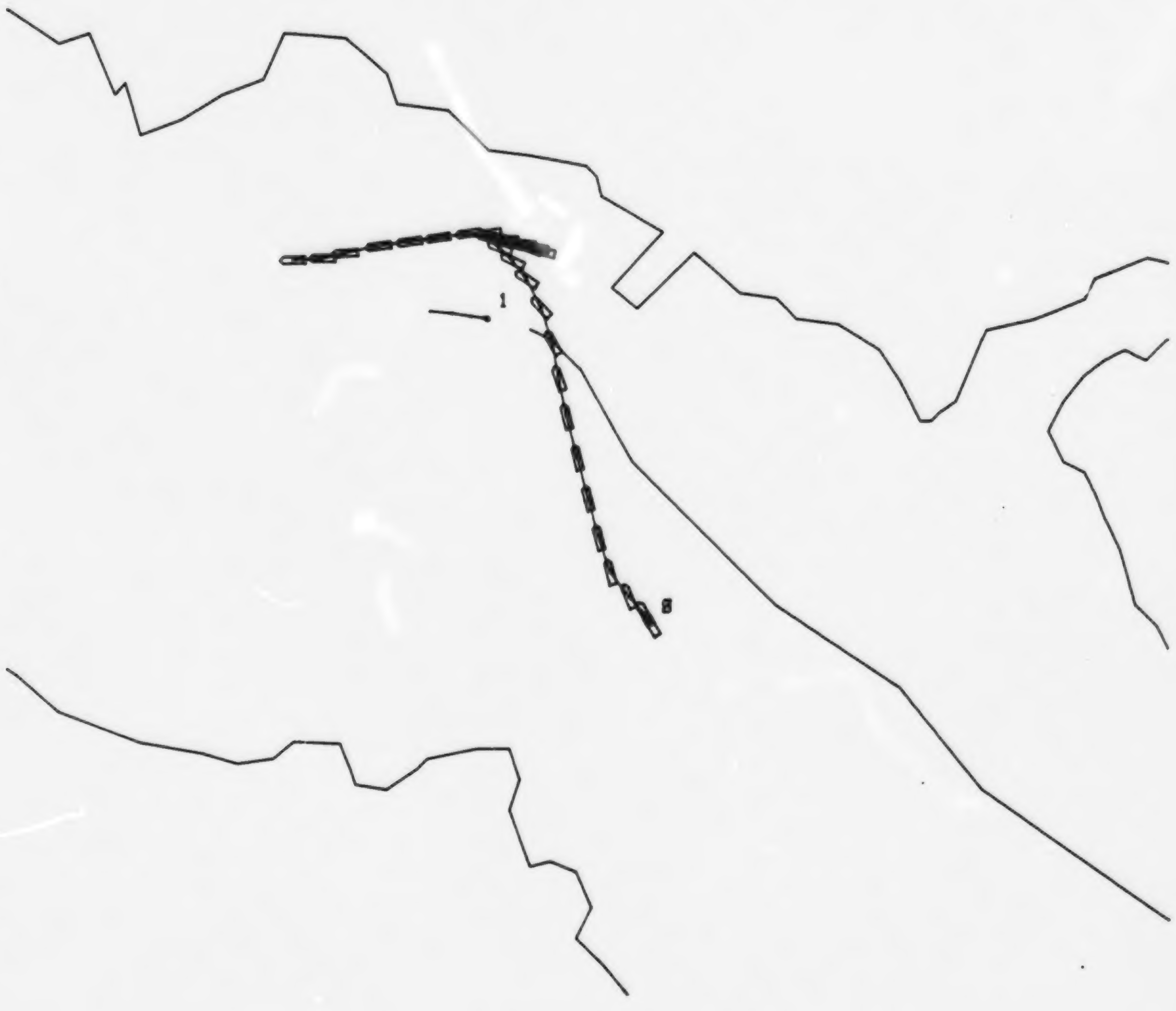
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 7 [✓ 8] 9 10

Run P80V
Date 04-03-88
Time 10:15
Pilot: P. TOOMEY



Polar Class- Exercise No.3

## VALIDATION FORM

### EVALUATING THE SHIP'S MODEL

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 [✓ 7] 8 9 10

Astern 1 2 3 4 5 6 [✓ 7] 8 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 [✓ 6] 7 8 9 10

Astern 1 2 3 4 5 [✓ 6] 7 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

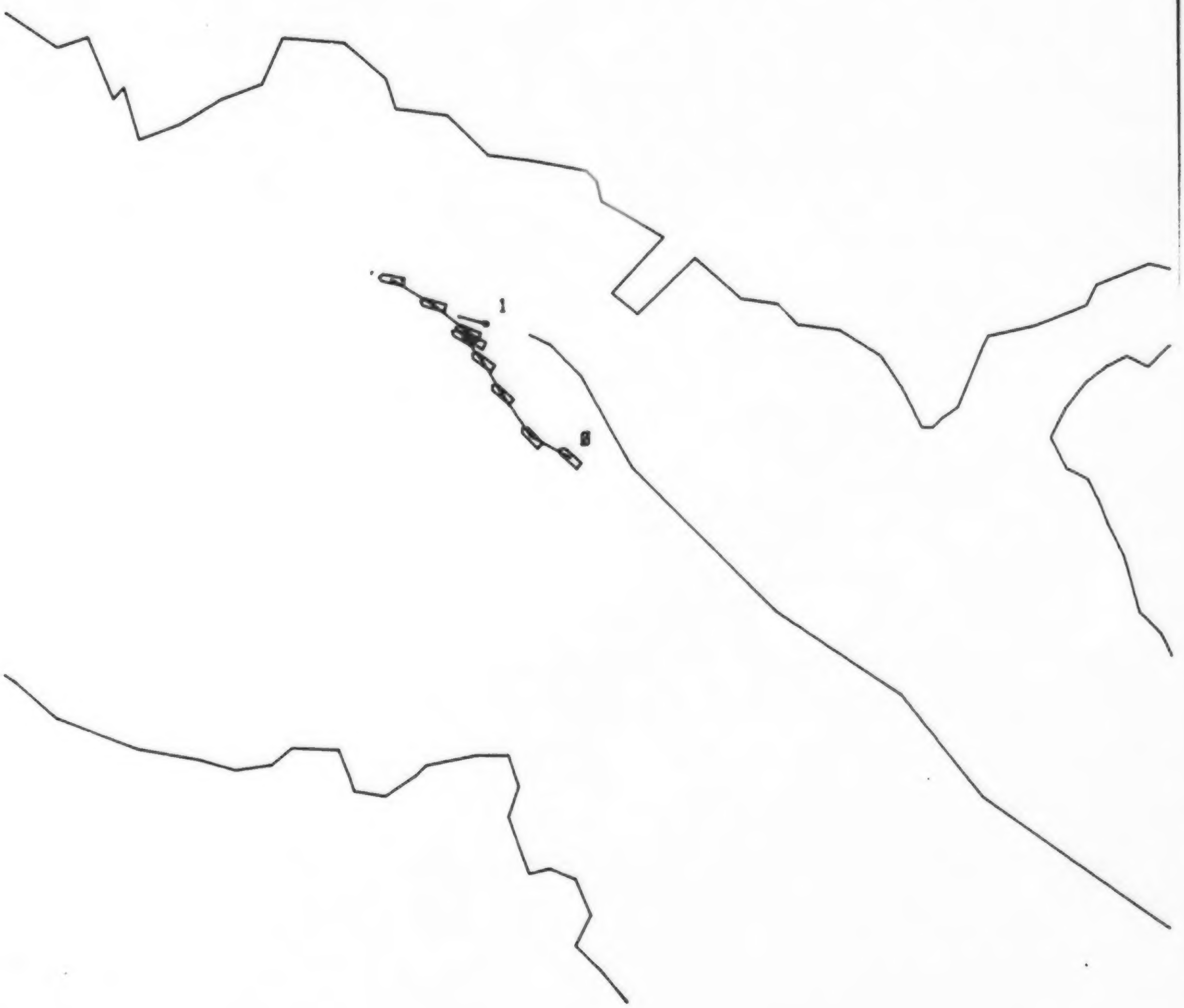
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 7 [✓ 8] 9 10

| | |
|---|---|
| Run | P160V |
| Date | 04-03-88 |
| Time | 10:55 |
| Pilot: | P. TOOMEY |



Polar Class Exercise

VALIDATION FORM

## EVALUATING THE SHIP'S MODEL

Please rank from 1 to 10 the following items to indicate how realistic they are, the higher the rank, the more realistic the item: (Circle the right number).

1. The rate of acceleration

Ahead 1 2 3 4 5 6 [✓ 7] 8 9 10

Astern 1 2 3 4 5 6 [✓ 7] 8 9 10

2. The rate of deceleration

Ahead 1 2 3 4 5 [✓ 6] 7 8 9 10

Astern 1 2 3 4 5 [✓ 6] 7 8 9 10

3. The rate of turn (as a result of the rudder's angle)

To Starboard 1 2 3 4 5 6 7 [✓ 8] 9 10

To Port 1 2 3 4 5 6 7 [✓ 8] 9 10

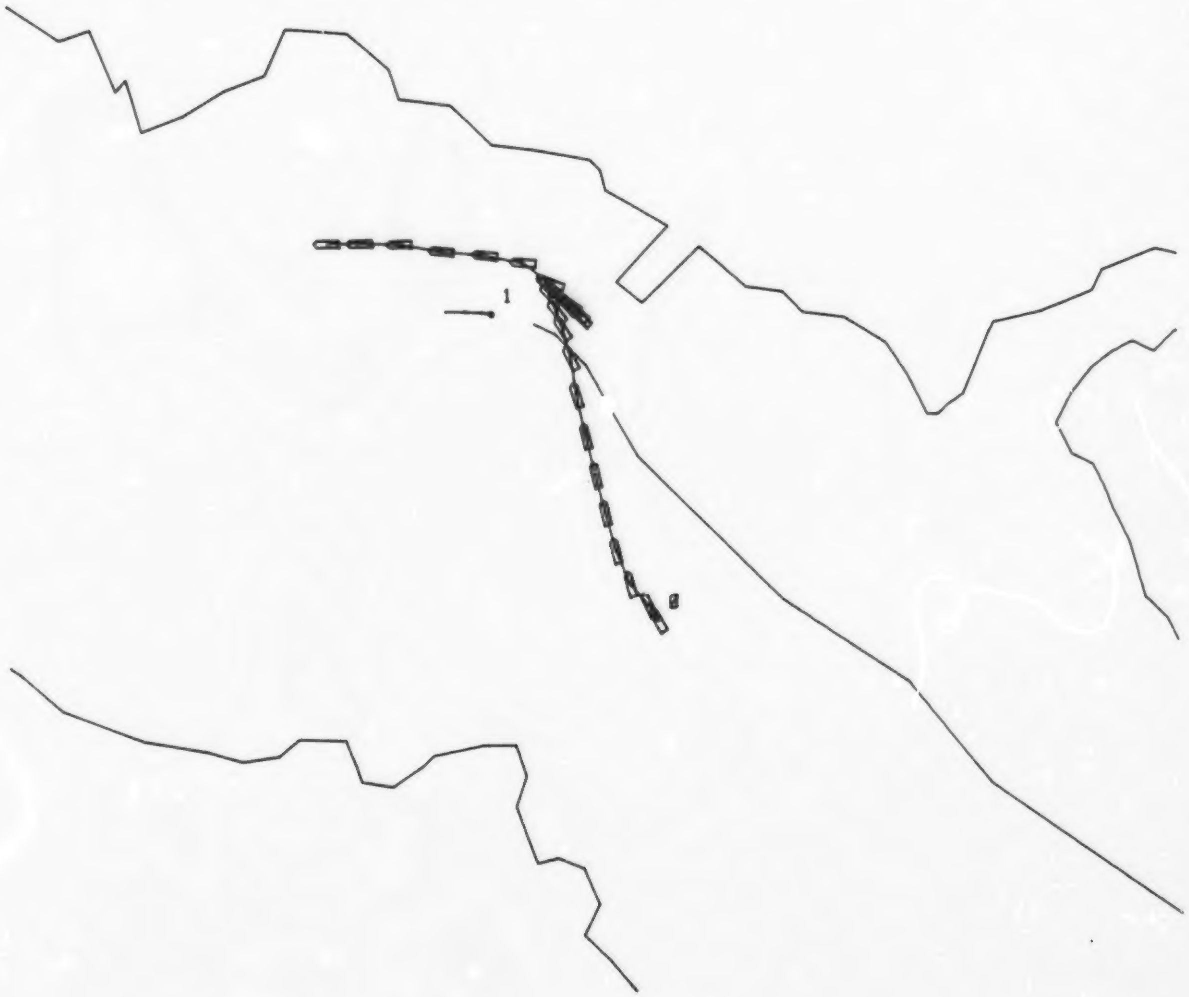
4. The rate of turn (as a result of using the propellers one ahead and one astern.

To Starboard 1 2 3 4 5 6 [✓ 7] 8 9 10

To Port 1 2 3 4 5 6 [✓ 7] 8 9 10

5. The rate of turn (as a result of using the propellers and the rudder). 1 2 3 4 5 6 [✓ 7] 8 9 10

| | |
|---|---|
| Run | P80XF |
| Date | 04-03-88 |
| Time | 11:25 |
| Pilot: | P. TOOMEY |



# APPENDIX B

# EVALUATION FORMS

Capt. Hann

## FINAL EVALUATION FORM

### A. BRIDGE INSTRUMENTS

Please rank the following items from 1 to 10 to indicate how realistic they are. The higher the rank the more realistic the item (circle the right number):

| | |
|---|---|
| 1. Navigation Lights | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| 2. Communication | |
| - External (VHF)<br>- Internal (telephone) | 1 2 3 4 5 6 7 8 [✓ 9] 10 |
| 3. Rudder angle indicator | |
| - Wheel Indicator (Helm) | 1 2 3 4 5 6 7 8 [✓ 9] 10 |
| - Actual Rudder Position (Overhead) | 1 2 3 4 5 6 7 8 [✓ 9] 10 |
| 4. The rudder response time (the time between moving the wheel to the desired position and when the rudder is actually there). | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| 5. The engine response time (the time between setting the throttles at the desired speed and when the RPM indicators indicate the correct reading). | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| 6. Ship's head | |
| - Heading Indicator | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| - Steering Gyro Repeater | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| 7. Radar Simulated Image (general) | 1 2 3 4 5 6 [✓ 7] 8 9 10 |
| 8. Speed Indicator | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| 9. Depth Indicator | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| 10. RPM Indicator | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| 11. Propeller Throttles | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| 12. Chart Room & Charts | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| 13. Layout of the Bridge Instruments | 1 2 3 4 5 6 7 [✓ 8] 9 10 |

## B. EVALUATING THE GAMING AREA

Please indicate the level of adequacy of the items below to the Simulation process. The higher the number the more adequate the item: (Please circle the level of adequacy).

### B.1 'Out of the window' visuals:

1.1 The number of reference points included as a part of the shoreline. 1 2 3 4 5 6 7 [✓ 8] 9 10

1.2 The number of lights shown in the nocturnal view:

Lights in General 1 2 3 4 5 6 7 [✓ 8] 9 10

Lights Indicating the Reference Points 1 2 3 4 5 6 7 [✓ 8] 9 10

The number of lights indicating the target ship. 1 2 3 4 5 6 7 [✓ 8] 9 10

### B.2 Radar Simulated Image

2.1 Detail of Shorelines 1 2 3 4 5 6 7 8 [✓ 9] 10

2.2 Target Ship Picture 1 2 3 4 5 6 [✓ 7] 8 9 10

2.3 Details of ship's own track in ice 1 2 3 4 5 6 7 8 [✓ 9] 10

2.4 Obtainable information offering safe navigation (Range and bearing, etc.) 1 2 3 4 5 6 7 8 [✓ 9] 10

### B.3 Radar Ranges (Please Circle the Appropriate Radar Range)

The most frequent range used [✓ 0.75] 1.5 3.0 6.0

The smallest range used [✓ 0.75] 1.5 3.0 6.0

The largest range used [✓ 3.0] 6.0 12.0 24.0

## C. MATHEMATICAL SHIP'S MODEL

Please comment on the following:

1. Representation of ship's manoeuvrability on a simulator:

GOING AHEAD VERY REALISTIC

GOING ASTERN THE SHIP HAD A TENDENCY TO GO 90° TO THE ACTUAL DIRECTION IT WOULD NORMALLY GO.

2. Gaining experience by operating a ship model on the simulator when you don't have any experience of operating such a ship in the real life (Polar Class ship model).

GOING AHEAD WITH BOTH ENGINES AHEAD THE RUDDER RESPONSE WAS REALISTIC. IT WAS QUITE NOTICABLE WITH DIFFERENT ICE THICKNESS.

## D. VISUALS

1. Was the nocturnal view sufficient for the simulation of manoeuvring in ice? How satisfactory/unsatisfactory? and Why?

IT IS VERY DIFFICULT WITHOUT DAYLIGHT EFFECTS.

2. Do you think that having the daylight view will improve the value of research and/or training?

MOST DEFINATELY. WITHOUT DAYLIGHT IT WILL BE VERY DIFFICULT TO APPRECIATE DIFFERENT ICE CONDITION.

3. Are there any additional features that can be added to the Simulator to make it more realistic without having daylight view? (Sound, Vibration, motion, etc.).

IT WILL MAKE MORE REALISTIC TO HAVE SOUNDS BUT DAYLIGHT WILL BE MORE IMPORTANT

4. Was the configuration of the lights of the target ship appropriate in simulating the real life situation? Do you prefer a better presentation of the target ship? Please specify.

NO, THE CONFIGURATION OF LIGHTS WAS SATISFACTORY.

## E. SCENARIOS

1. Were they complex or simple? Why? (Please write your own suggestions).

THE SCENARIOS COVERED MOST SITUATIONS.

2. What can be added as a part of the scenario to make it more realistic?

DAYLIGHT EFFECTS.

3. Comment on the feeling of ice restricting the manoeuvrability of ships presented on the simulator?

THE WHOLE EXERCISE WAS REAL EXCEPT WITH HAVE ONE ENGINE AHEAD AND THE OTHER ASTERN BECAUSE THE SHIP WOULD GO PERPENDICULAR TO THE ACTUAL HEADING. SIMULATE BROKEN CHANNEL.

## F. GENERAL COMMENTS

Write in this part your opinion of the whole process of simulating ship handling in ice and how it can be modified depending on your experience in using the Simulator in comparison to the real life situations.

THE DAYLIGHT EFFECT SHOULD BE INCLUDED FOR THE NAVIGATOR TO APPRECIATE WHAT DIFFERENT TYPES OF ICE LOOK LIKE. IF NOT, I CAN SEE SOME ONE THAT ONLY HAVE SIMULATOR EXPERIENCE CAUSING ICE DAMAGE IN REAL LIFE SITUATIONS.

CAPT. P.R.M. TOOMEY. C.C.G.
OTTAWA.

## FINAL EVALUATION FORM

### A. BRIDGE INSTRUMENTS

Please rank the following items from 1 to 10 to indicate how realistic they are. The higher the rank the more realistic the item (circle the right number):

| | |
|---|---|
| 1. Navigation Lights | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| 2. Communication | |
| - External (VHF) | 1 2 3 4 5 6 7 8 [✓ 9] 10 |
| - Internal (telephone) | |
| 3. Rudder angle indicator | |
| - Wheel Indicator (Helm) | 1 2 3 4 5 6 7 8 [✓ 9] 10 |
| - Actual Rudder Position (Overhead) | 1 2 3 4 5 6 7 8 [✓ 9] 10 |
| 4. The rudder response time (the time between moving the wheel to the desired position and when the rudder is actually there). | 1 2 3 4 5 6 7 8 [✓ 9] 10 |
| 5. The engine response time (the time between setting the throttles at the desired speed and when the RPM indicators indicate the correct reading). | 1 2 3 [✓ 4] 5 6 7 8 9 10 |
| 6. Ship's head | |
| - Heading Indicator | 1 2 3 4 5 6 7 8 [✓ 9] 10 |
| - Steering Gyro Repeater | 1 2 3 4 5 6 7 8 9 10 |
| 7. Radar Simulated Image (general) | 1 [✓ 2] 3 4 5 6 7 8 9 10 |
| 8. Speed Indicator | 1 2 3 4 5 6 [✓ 7] 8 9 10 |
| 9. Depth Indicator | 1 2 3 4 5 6 7 [✓ 8] 9 10 |
| 10. RPM Indicator | 1 2 3 4 5 6 7 8 [✓ 9] 10 |
| 11. Propeller Throttles | 1 2 3 4 5 6 7 8 [✓ 9] 10 |
| 12. Chart Room & Charts | 1 2 3 4 5 6 7 8 [✓ 9] 10 |
| 13. Layout of the Bridge Instruments | 1 2 3 4 5 6 [✓ 7] 8 9 10 |

## B. EVALUATING THE GAMING AREA

Please indicate the level of adequacy of the items below to the Simulation process. The higher the number the more adequate the item: (Please circle the level of adequacy).

### B.1 'Out of the window' visuals:

1.1 The number of reference points included as a part of the shoreline. 1 2 3 4 5 6 [✓ 7] 8 9 10

1.2 The number of lights shown in the nocturnal view:

Lights in General 1 2 3 4 5 6 [✓ 7] 8 9 10

Lights Indicating the Reference Points 1 2 3 4 5 [✓ 6] 7 8 9 10

The number of lights indicating the target ship. 1 2 3 4 [✓ 5] 6 7 8 9 10

### B.2 Radar Simulated Image

2.1 Detail of Shorelines 1 2 3 4 5 6 [✓ 7] 8 9 10

2.2 Target Ship Picture 1 [✓ 2] 3 4 5 6 7 8 9 10

2.3 Details of ship's own track in ice 1 2 3 [✓ 4] 5 6 7 8 9 10

2.4 Obtainable information offering safe navigation (Range and bearing, etc.) 1 2 3 4 5 [✓ 6] 7 8 9 10

### B.3 Radar Ranges (Please Circle the Appropriate Radar Range)

The most frequent range used 0.75 [✓ 1.5] 3.0 6.0

The smallest range used [✓ 0.75] 1.5 3.0 6.0

The largest range used [✓ 3.0] 6.0 12.0 24.0

## C. MATHEMATICAL SHIP'S MODEL

Please comment on the following:

1. Representation of ship's manoeuvrability on a simulator:

TURNING USING OPPOSED PROPELLORS WORKS BETTER WITH NO HEADWAY ON THE SIMULATOR. IN REAL LIFE HEADWAY WOULD BE NECESSARY IN ICE TO MAKE HER TURN, UNLESS SHE WERE TO BE IN A POOL OF BROKEN ICE.
THE SHIP DOES NOT BACK DOWN HER CUT CHANNEL ON THE SIMULATOR, BUT MOVES DIRECTLY ASTERN ALONG THE RECIPROCAL HEADING.
THERE IS NO TENDENCY TO FOLLOW A CUT TRACK.

2. Gaining experience by operating a ship model on the simulator when you don't have any experience of operating such a ship in the real life (Polar Class ship model).

SOME IDEA CAN BE OBTAINED THAT THERE IS A DIFFERENCE IN BEHAVIOUR BETWEEN DIFFERENT CLASSES OF SHIP, BUT THERE IS A TENDENCY TO "PLAY THE MACHINE" DUE TO THE LACK OF SENSUAL PERCEPTION OF WHAT IS HAPPENING, THE PILOT HAS TO RELY ALMOST EXCLUSIVELY ON ELECTRONICALLY PRESENTED INFORMATION, WHICH IS DANGEROUS TO EMPLOY IN REAL LIFE.

## D. VISUALS

1. Was the nocturnal view sufficient for the simulation of manoeuvring in ice? How satisfactory/unsatisfactory? and Why?

BARELY SUFFICIENT BECAUSE THE PILOT IS DEPRIVED OF THE TOOLS, SUCH AS SEARCHLIGHTS, USED IN REAL LIFE TO JUDGE DISTANCE, ICE CONDITIONS ETC.
THE TARGET SHIP MOVES OUT OF SIGHT MUCH TOO SOON.
THE SHIP HAS NO SILHOUETTE FOR THE HULL AND CLOSE ABOARD LOSES CREDIBILIT

2. Do you think that having the daylight view will improve the value of research and/or training?

THE VALUE CAN BE GREATLY IMPROVED FOR TRAINING HAVING DAYLIGHT VIEW BECAUSE CLOSE QUARTERS WORK IS A MATTER OF EYE JUDGEMENT. IF THE ICE CONDITIONS CAN ALSO BE SIMULATED THEN THE REAL WORLD IS BEGINNING TO BE REPRESENTED.

3. Are there any additional features that can be added to the Simulator to make it more realistic without having daylight view? (Sound, Vibration, motion, etc.).

ADD WRAP-AROUND VISUALS TO AT LEAST 4 POINTS ABAFT THE BEAM ON BOTH SIDES.
VIBRATION FROM SCREW INTERACTION WITH ICE, GOING ASTERN. THIS CAN BE A WARNING WHEN SAFE OPERATION IS BEING EXCEEDED.

4. Was the configuration of the lights of the target ship appropriate in simulating the real life situation? Do you prefer a better presentation of the target ship? Please specify.

THERE ARE TOO FEW LIGHTS ALONG THE LENGTH OF THE SHIP WHEN CLOSE ABOARD THE LIGHTS ARE TOO HIGH AND ONLY AT DISTANCES GREATER THAN 5 CABLES IS THERE MUCH SENSE OF REALISM. IT IS HARD TO KNOW THE LIMIT OF THE BOW WHEN CLOSE TO THE STEM.

## E. SCENARIOS

1. Were they complex or simple? Why? (Please write your own suggestions).

THE SCENARIOS WERE GENERALLY SIMPLE, THE TARGET SHIP WAS ALWAYS AT APPROXIMATELY THE DESIRED HEADING AND THE ICEBREAKER WAS ALWAYS STARTING FROM SOMEWHERE ABAFT HER BEAM. SOME EXERCISES SHOULD BE DONE WITH THE VESSELS STARTING FACING OPPOSITE DIRECTIONS, A SHIP PLACED CLOSE INSHORE LIMITS THE CHOICE OF ACTION FOR THE ICEBREAKER.

2. What can be added as a part of the scenario to make it more realistic?

AS ABOVE, ALSO TO TURN THE TARGET SHIP AROUND TO HEAD OFF IN SOME MAJOR COURSE ALTERATION, FROM INITIAL POSITION.

INSERT TWO DIFFERENT KINDS OF ICE THICKNESS (NOT MIXED BUT SEPARATE AREAS) SO THAT ICEBREAKER BEHAVIOUR HAS TO BE MODIFIED.

USE A LOW POWERED TARGET SHIP WHICH REQUIRES MUCH MORE ASSSTANCE

3. Comment on the feeling of ice restricting the manoeuvrability of ships presented on the simulator?

MANOEUVRABILITY WAS DEFINITELY AFFECTED AND RESTRICTED IN DIFFERENT WAYS WHEN "R"-CLASS WAS COMPARED TO POLAR-CLASS. I HAD A BIG PROBLEM WITH ACCELERATIONS AND DECELERATIONS WHICH SEEMED TO BE MUCH TOO RAPID. THERE WAS NO FEELING THAT WAY WAS BEING CARRIED WITH ENGINES AT "STOP". SAME FOR STEERING, HELM ON MIDSHIP WAS ENOUGH FOR A STEADY COURSE, NO NEED TO STEER AND NO SURPRISES.

## F. GENERAL COMMENTS

Write in this part your opinion of the whole process of simulating ship handling in ice and how it can be modified depending on your experience in using the Simulator in comparison to the real life situations.

SIMULATING SHIP-HANDLING IN ICE THUS FAR IS NOT SUFFICIENTLY ADVANCED FOR TRAINING ANYONE IN ICE NAVIGATION BUT COULD INTRODUCE THE NAVIGATOR TO SOME OF THE PROBLEMS HE WILL MEET IN ICE, IF HE HAS NEVER BEFORE BEEN THERE. IT MUST BE MODIFIED TO REFLECT REALITY WITH "READING THE ICE CONDITIONS", IN DAYLIGHT GRAPHICS WITH SUFFICIENT FIELD OF VIEW AS TO PREVENT DISORIENTATION. MIXED ICE CONDITIONS (± 20%) AT THE THINNER END OF THE SCALE MAKE SO LITTLE DIFFERENCE TO PERFORMANCE THAT THEY ARE WORTHLESS.
AT THE THICK END, MIXED CONDITIONS ARE USEFUL IN FINE GRID ONLY BECAUSE ALL THE ACTION TAKES PLACE CLOSE ABOARD THE TARGET VESSEL, TENDING TO REMAIN IN ONLY ONE OR TWO GRID SQUARES.